THE AMERICAN
PETROLEUM INDUSTRY

VOLUME I

THE AMERICAN PETROLEUM INDUSTRY

VOLUME I

BY

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"PETROLEUM IS A PRICELESS RESOURCE, FOR IT CAN NEVER BE REPLACED . . . . TO INDUSTRY, AGRICULTURE, COMMERCE, AND THE PLEASURES OF LIFE PETROLEUM IS NOW ESSENTIAL."

FRANKLIN K. LANE.

PREFACE

The purpose of the authors in preparing this work has been to produce a treatise which would present a comprehensive survey of the American petroleum industry, distinctly modern in every respect, and suitable not only as a general reference work for those engaged in the industry but also as a text-book for students of petroleum engineering. For these reasons, the subject matter is essentially descriptive, without, however, omitting the theoretical considerations necessary for the proper understanding of the subjects included.

While it is by no means a composite work, the authors have been fortunate in securing the collaboration of authorities, as writers on subjects with which they are especially qualified to treat. The names of Messrs. F. G. Clapp, E. E. Greve, Roswell H. Johnson, J. P. Cappeau, and L. G. Huntley are a guarantee that no pains have been spared to make the work a faithful record of the present knowledge of the American petroleum industry. Six of the eighteen chapters constituting the treatise have been prepared with the full coöperation of these experts; the other twelve chapters deal with such subjects as are within the knowledge and experience of the authors, and it has not therefore been necessary to arrange for their preparation by others. It must be mentioned here, however, that Mr. George H. Taber, Vice-President of the Gulf Refining Company, Pittsburgh, Pa., and a recognized authority on petroleum technology, has critically read the entire manuscript and has made numerous valuable suggestions, especially on the treatment of the subject of refinery technology. It is a real pleasure for the authors to acknowledge their deep indebtedness to Mr. Taber and to Mr. Wesley A. Looney, General Manager of the Gulf Refining Company, for their mature advice, helpful criticisms and courteous interest.

The acknowledgments of the authors are also due to the various refiners of petroleum and to the manufacturers of refinery equipment who have supplied descriptive information, engineering data and photographs; and to the Director of the United States Geological Survey and the Director of the Bureau of Mines for

their kind concurrence. F. W. Clarke's monumental work, "The Data of Geochemistry" (Bulletin 616 of the United States Geological Survey), has been freely drawn from in the production of Chapter I; while "The Mineral Resources of the United States" has been an invaluable repository of needed statistical information. The publications of the Bureau of Mines which have been used in the preparation of this work, are mentioned in place. Report No. 291 of the Mines Branch, Canada Department of Mines, has been of real aid in the composition of Chapter VI.

The authors ask the indulgence of the reader for any errors or omissions that occur in the present volumes. In a work of this character, covering so large and progressive a field, an early revision will probably be desirable, and the authors will accordingly be grateful for any suggestions with this end in view that may be submitted to them. Comparatively little space is devoted to the geology and production of crude petroleum; for further information on these subjects, the reader is referred to Johnson and Huntley's "Principles of Oil and Gas Production" (New York, 1916). Then, too, the law relating to oil properties has been purposely omitted: this subject is considered at length in G. Bryan's "Law of Petroleum and Natural Gas," 1898, and in W. W. Thornton's "Law relating to Oil and Gas," 1904; oil-land law is discussed by G. O. Smith in *Trans. Am. Inst. Min. Eng.*, **48** (1915), 443; and M. W. Ball has considered the placer law as applied to petroleum in *idem*, 451.

No list of the abbreviations of the titles of the technical periodicals cited has been prepared for the reason that the standard journal list of the American Chemical Society has been followed (see *Chemical Abstracts*, December 20, 1915).

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THE MELLON INSTITUTE OF INDUSTRIAL RESEARCH,
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THE AMERICAN PETROLEUM INDUSTRY

VOLUME I

CHAPTER I

THE GEOCHEMISTRY OF PETROLEUM

THE COMPOSITION OF PETROLEUM

Petroleum[1] is a naturally occurring liquid of great economic importance—the most valuable of the bitumens. It is, like natural gas and asphaltum, an extremely complex mixture of compounds of carbon and hydrogen. Moreover, it contains many widely varying substances in small amounts—sulphur compounds, products of oxidation, nitrogenous substances, etc.—whose exact nature is not always clearly defined.[2]

[1] An early use of the word petroleum is found in the Wardrobe Account, 21–23 Edw. III., $^{38}/_{2}$, which contains this entry: "Delivered to the King in his chamber at Calais: 8 lb. petroleum." *N. and Q.*, (7), **5**, 248. The word petroleum was used by Konrad Kyeser in 1646 (Feldhaus, *Petroleum*, **5**, 633). It is derived from the Latin *petra*, rock + *oleum*, oil.

Petroleum has been legally defined as follows (Kier *vs.* Peterson, *Pa. St.*, **41**, 361): "Petroleum or rock oil is essentially composed of carbon and hydrogen, and is a liquid inflammable substance or bitumen exuding from the earth. It is collected in various parts of the world, on the surface of the water, in wells and fountains, or oozing from cavities in rocks." For a definition of petroleum as used in an English Act regulating the keeping and sale of petroleum, see Beck *vs.* Stringer, *L. R.*, **6** *Q. B.*, 504.

Oil direct from the well should always be designated "crude petroleum" in preference to "crude oil" (on this point, see Donath, *Chem.-Ztg.*, **37**, 661); the simple term "oil" is widely used by geologists.

Regarding the early history of petroleum, see Boverton Redwood's "A Treatise on Petroleum," 3d ed., **1**, 1–3. It may be noted here that it was used by the Medes and Persians in religious ceremonies and as a fuel for lamps in the second century (von Lippmann, *Chem.-Ztg.*, **35**, 537). A full historical account of the American petroleum industry is given in Chap. V (pp. 197 to 271).

[2] The proximate analysis of petroleum consists in separating its components from one another, and in their identification as compounds of definite constitution. On the *analytical characteristics* of American petroleums, see pp. 122 to 196.

Different petroleums are composed roughly of 13 to 11 per cent. of hy-

All the hydrocarbons fall primarily into a number of regular series, to each of which a generalized formula may be assigned, in accordance with the following scheme:

Members of these have been found in petroleum.	1. C_nH_{2n+2}.[1]	....
	2. C_nH_{2n}.[2]	....
	3. C_nH_{2n-2}.[3]	....
	4. C_nH_{2n-4}.	....
	5. C_nH_{2n-6}.	....
	6. C_nH_{2n-8}.	....
	7. C_nH_{2n-10}.	....
	8. C_nH_{2n-12}.	....
	9. C_nH_{2n-14}.[4]	18. C_nH_{2n-32}.

Each of these expressions represents a group of series—homologous, isomeric, or polymeric, which, for precise work, must be considered separately. The first formula, for example, represents what are known as the paraffin hydrocarbons, which begin with *methane*, CH_4, and range at least as high as the compound $C_{35}H_{72}$. These are again subdivided into a number of isomeric series—the *primary, secondary,* and *tertiary. paraffins*—which, with equal percentage composition, differ in physical properties owing to differences of atomic arrangement within the molecules. Each member of the series differs from the preceding member by the addition of the group CH_2, and also by certain physical characteristics. For instance, methane is gaseous; the middle members of the series are liquids, with regularly increasing boiling points; the higher members are solids, like ordinary paraffin. These hydrocarbons preponderate in the Pennsylvania petroleums, from which the members of the series given in Table 1 have been separated.

The isomeric secondary paraffins *isobutane, isopentane, isohexane, isoheptane,* and *isooctane* should be included in this list, and even then it is undoubtedly incomplete. For instance, the solid paraffins $C_{27}H_{56}$ and $C_{30}H_{62}$ have been found in petroleum.

drogen and 84 to 87 per cent. of carbon; the hydrocarbons present are numbered by the hundred. On the *relations of the various bituminous materials*, see p. 853.

[1] Especially in Pennsylvania and Galician petroleums.

[2] These preponderate in the petroleums of Burma, and are abundant in those from Baku and California.

[3] On C_nH_{2n-2} hydrocarbons in Ohio petroleums, see MABERY, *J. Ind. Eng. Chem.*, **6** (1914), 101.

[4] In certain Russian and Rumanian petroleums.

TABLE I.—PARAFFINS FROM PENNSYLVANIA PETROLEUM

Name	Formula	Melting point	Boiling point
1. Gaseous:		°C.[2]	°C.
Methane	CH_4	−184.0	−165.0
Ethane	C_2H_6	−171.4	− 93.0
Propane	C_3H_8	−195	− 45.0
Butane	C_4H_{10}	−135	+ 1.0
2. Liquid:			
Pentane	C_5H_{12}	....	36.3
Hexane	C_6H_{14}	....	69.0
Heptane	C_7H_{16}	....	98.4
Octane	C_8H_{18}	....	125.5
Nonane	C_9H_{20}	− 51.0	150.0
Decane	$C_{10}H_{22}$	− 31.0	173.0
Undecane	$C_{11}H_{24}$	− 26.0	195.0
Dodecane	$C_{12}H_{26}$	− 12.0	214.0
Tridecane	$C_{13}H_{28}$	− 6.0	234.0
Tetradecane	$C_{14}H_{30}$	+ 5.0	252.0
Pentadecane	$C_{15}H_{32}$	10	270.0
Hexadecane	$C_{16}H_{34}$	18.0	287.0
3. Solid:			
Octadecane	$C_{18}H_{38}$	28.0	317.0
Eicosane	$C_{20}H_{42}$	37.0	....
Tricosane	$C_{23}H_{48}$	48.0	....
Tetracosane	$C_{24}H_{50}$	51.0	....
Pentacosane	$C_{25}H_{52}$	53–54.0	....
Hexacosane	$C_{26}H_{54}$	55–56.0	....
Octocosane	$C_{28}H_{58}$	60.0	....
Nonocosane	$C_{29}H_{60}$	62–63.0	....
Hentriacontane	$C_{31}H_{64}$	68.0	....
Dotriacontane	$C_{32}H_{66}$	70.0	....
Tetratriacontane	$C_{34}H_{70}$	71–72.0	....
Pentatriacontane[1]	$C_{35}H_{72}$	75.0	....

Unsaturated open-chain hydrocarbons, probably of the series C_nH_{2n}, are, as constituents of petroleum, of considerable importance. These fall into several independent series, which differ in physical properties and in their chemical relations, although identical in percentage composition. Of one series,

[1] For a description of these higher, solid paraffins, see MABERY, *Am. Chem. J.*, **33** (1905), 251. HELL and HÄGELE (*Ber.*, **22** (1889), 504) have described the artificial hydrocarbon $C_{60}H_{122}$.

[2] All temperature designations used in this treatise refer to degrees Centigrade, unless otherwise stated.

the olefines, which is parallel to the paraffin series, the following members have been isolated from petroleum:[1]

TABLE II.—SO-CALLED "OLEFINES" ISOLATED FROM PETROLEUM

Name	Formula	Melting point	Boiling point
1. Gaseous:		°C.	°C.
Ethylene	C_2H_4	−169.0	−102.7
Propylene	C_3H_6	....	− 50.2
Butylene	C_4H_8	....	+ 1.0
2. Liquid:			
Amylene	C_5H_{10}	....	+ 36.0
Hexylene	C_6H_{12}	....	69.0
Heptylene	C_7H_{14}	....	98.0
Octylene	C_8H_{16}	....	122.5
Nonylene	C_9H_{18}	....	141.0
Decylene	$C_{10}H_{20}$	....	175.0
Undecylene	$C_{11}H_{22}$	....	196.0
Dodecylene	$C_{12}H_{24}$	− 31.0	213.0
Tridecylene	$C_{13}H_{26}$	....	232.7
Cetene	$C_{16}H_{32}$	+ 4.0	275.0
Eicosylene	$C_{20}H_{40}$	....	395.0
3. Solid:			
Cerotene	$C_{27}H_{54}$	58.0	....
Melene	$C_{30}H_{60}$	62.0	....

As Clarke observes,[2] this table is probably exact in an empirical sense, but not so constitutionally. Hydrocarbons of the indicated composition have undoubtedly been found, and some of them are certainly olefines. According to Mabery,[3] however, the true olefines, the "open-chain" series, are present in petroleum at most in very small amounts. In Canadian petroleum Mabery and Quayle[4] identified *hexylene, heptylene, octylene,* and *nonylene.* In other cases, and notably in the Russian petroleums, the compounds C_nH_{2n} are not olefines, but cyclic hydrocarbons of the *polymethylene series,* which were originally called "*naphthenes.*" They were at first regarded as derivatives of the benzene series, and only recently has their true

[1] HÖFER'S "Das Erdöl," 2nd ed., 65.

[2] "Data of Geochemistry," **1911,** 684.

[3] *J. Am. Chem. Soc.,* **28** (1906), 415; cf. PICTET and BOUVIER, *Compt. rend.,* **160** (1915), 629.

[4] *Proc. Am. Acad.,* **41** (1905), 89.

constitution been determined. According to Mabery and Hudson,[1] they predominate in California petroleum.

Members of the series from C_7H_{14} were isolated from the California material. Mabery and Takano[2] reported that Japanese petroleum consisted largely of C_nH_{2n} hydrocarbons. Other similar occurrences are recorded in the treatises of Höfer

FIG. 1.—Dr. Charles Frederic Mabery, distinguished for his original contributions to the chemistry of American petroleum.

and Redwood.[3] Some Russian oils contain as much as 80 to 90 per cent. of "*naphthenes.*"

The lower members of the series C_nH_{2n-2} seem not to have been found in petroleum, although several of the higher members

[1] *Idem*, **36** (1901), 255.

[2] *Ibid.*, 295.

[3] HÖFER presents a full discussion of the composition of the various petroleums. In his "Wissenschaftliche Trundlagen der Erdölbearbeitung" (pp. 1 to 115), GURWITSCH covers in detail the composition of petroleums from the chemical and physical sides.

are characteristic of oils from Texas, Louisiana, and Ohio. In oil from the Trenton limestone of Ohio, Mabery and Palm[1] found hydrocarbons having the composition of $C_{19}H_{36}$, $C_{21}H_{40}$, $C_{22}H_{42}$, and $C_{24}H_{46}$. With these compounds were members of the C_nH_{2n} series as high as $C_{17}H_{34}$. There were also members of the next series, C_nH_{2n-4}, namely, $C_{23}H_{42}$, $C_{24}H_{44}$, and $C_{25}H_{46}$; members of this series occur generally in small amounts in all the crude oils of low specific gravity. In petroleum from Louisiana, Coates and Best[2] found the hydrocarbons $C_{12}H_{22}$ and $C_{14}H_{26}$. These, together with $C_{16}H_{30}$, were also separated by Mabery[3] from Texas oils. These oils also contain free sulphur, which separates out in crystalline form.[4] In heavy petroleum from Santa Barbara, Cal., Mabery[5] discovered hydrocarbons of the three series C_nH_{2n-2}, C_nH_{2n-4}, and C_nH_{2n-8},[6] represented by the formulas $C_{13}H_{24}$, $C_{16}H_{30}$, $C_{17}H_{20}$, $C_{18}H_{32}$, $C_{24}H_{44}$, $C_{27}H_{46}$, and $C_{29}H_{50}$.

Hydrocarbons of the well-known series C_nH_{2n-6}, the "*aromatic*" or *benzene series*, occur in all descriptions of petroleum, although generally in small amounts. Their empirical formulas, omitting consideration of isomeric compounds, follows:

Benzene	C_6H_6
Toluene	C_7H_8
Xylene	C_8H_{10}
Cumene	C_9H_{12}
Cymene	$C_{10}H_{14}$
Etc.	

According to Mabery,[7] Pennsylvania petroleum contains

[1] *Am. Chem. J.*, **33** (1905), 251.

[2] *J. Am. Chem. Soc.*, **25** (1903), 1153; see also COATES, *idem*, **28** (1906), 384.

[3] *Idem*, **23** (1901), 264. See also on Texas oils, RICHARDSON and WALLACE, *J. Soc. Chem. Ind.*, **20** (1901), 690; THIELE, *Am. Chem. J.*, **22** (1899), 489; PHILLIPS, *Bull.* No. **5**, *Univ. Texas*, 1902; HILL, *Trans. Am. Inst. Min. Eng.*, **33** (1903), 363; and FENNEMAN, *Bull. U. S. Geol. Surv.*, No. **282** (1906). FENNEMAN describes both Texas and Louisiana petroleums. On the composition of Kansas oils, see BUSHONG, *Kansas Univ. Geol. Survey*, **9** (1908), 303. In the same volume, 187, HAWORTH discusses the origin of oil and gas.

[4] See RICHARDSON and WALLACE, *J. Soc. Chem. Ind.*, **21** (1902), 316.

[5] *Am. Chem. J.*, **33** (1905), 270.

[6] MARKOVNIKOV and OGLOBLIN (*Ber.*, **16** (1883), 1873) have found, in Russian petroleum, members of the series C_nH_{2n-8}, C_nH_{2n-10}, and C_nH_{2n-12}.

[7] *J. Am. Chem. Soc.*, **28** (1906), 418.

small proportions of the lower members of this series, and Mabery and Hudson[1] found larger amounts of them, especially of the *xylenes*, in California oil. Numerous other examples might be cited, but they need not be mentioned here.[2] *Naphthalene*, $C_{10}H_8$, is probably the only compound of the series C_nH_{2n-12} which has been positively identified in petroleum. It was found by Warren and Storer[3] in Rangoon oil, and also by Mabery and Hudson in oil from California. In one of the latter's distillations of crude oil, so much naphthalene was present that the distillate solidified on cooling slightly. Even more complex hydrocarbons have been found in petroleum residues, but it is possible that they were formed during the process of refining and it is not certain that they were originally present in the natural oil.[4]

Small amounts of *oxidized bodies* are contained in many petroleums, occasionally complex acids, sometimes phenols. According to Mabery,[5] *phenolic bodies* are found in notable proportions in some California oils, but not in petroleum from the eastern part of the United States. Substances having the properties of phenols are present in small amounts in all the distillates from Baku petroleum.[6]

Petroleums usually contain *nitrogen*, from a trace up to 1 per cent. and over. It may be said to exist in most cases, if not in all, in the form of complex organic bases, but the constitution of these remains to be determined. They are peculiarly abundant, as, probably, *pyridine* and *quinoline derivatives*, in California petroleum, in which they were discovered by Peckham;[7] and Mabery[8] has shown that in some cases the basic nitrogen

[1] *Proc. Am. Acad.*, **36** (1890), 255.

[2] Zaloziecki and Hausmann (*Z. angew. Chem.*, **1907**, 1761) have called attention to the richness of Rumanian petroleum in aromatic hydrocarbons.

[3] *Mem. Am. Acad.*, (2), **9** (1865), 208.

[4] For data and references, see Höfer, "Das Erdöl," p. 74; and pp. 579 and 592 of this treatise.

[5] *J. Am. Chem. Soc.*, **28** (1906), 596.

[6] *Ber.*, **7** (1874), 1216; **10** (1877), 451. See also Aschan, *Ber.*, **23** (1893), 867; **24** (1894), 1864; **25** (1895), 3661. On the products of the oxidation of petroleum, see pp. 581, 620 and 803. On naphthenic acids, see p. 888.

[7] *Am. J. Sci.*, (3), **48** (1894), 250; *Rept. Geol. Survey Cal.*, **2**, 89.

[8] *J. Soc. Chem. Ind.*, **19** (1900), 505. Bandrowski (*Monatsh. Chem.*, **8** (1887), 224) and Weller (*Ber.*, **20** (1887), 2097) have detected nitrogenous bases in European oils.

compounds constitute from 10 to 20 per cent. of the crude petroleum. Mabery isolated compounds of this class ranging from $C_{12}H_{17}N$ to $C_{17}H_{21}N$, although these formulas are open to question. Pennsylvania oils contain only traces of nitrogen.

Petroleum free from *sulphur* is very rare, although the amount of this constituent present is generally small. In some instances, however, the *sulphur compounds* are quite abundant, as, for example, in the Lima oil of Ohio, in which Mabery and Smith[1] found normal sulphides of the paraffin series $[(C_nH_{2n-1})_2S]$, and isolated ten compounds ranging from *methyl sulphide*, C_2H_6S, to *hexyl sulphide*, $C_{12}H_{26}S$. In Canadian petroleum Mabery and Quayle[2] found another series of sulphur compounds, cyclic in character and polymethylene derivatives, of the general formula $C_nH_{2n}S$, which they termed "*thiophanes;*" eight members of this series were described, between $C_7H_{14}S$ and $C_{18}H_{36}S$. Other sulphur compounds have been noted as occasional admixtures in petroleum,[3] and it remains to be mentioned that Richardson and Wallace[4] separated sulphur in the form of crystals from Beaumont petroleum, and Thiele[5] found 63.63 per cent. of *amorphous sulphur* and 6.81 per cent. of *crystalline sulphur* in the sediment in a tank car which had held Beaumont oil. *Hydrogen sulphide* is usually emitted by petroleums which contain sulphur in considerable amounts, especially on distillation.[6]

THE SYNTHESIS OF PETROLEUM

Hydrocarbons such as methane, ethane, acetylene, and benzene, have been often obtained by laboratory methods from inorganic sources, and also by the breaking down of more complex organic matter. Certain of the procedures employed have led to the production of substances resembling petroleum.[7]

[1] *Am. Chem. J.*, **13** (1891), 233.

[2] *Proc. Am. Acad.*, **41** (1905), 89. A paper by KAYSER, published in 1897, contains data relative to sulphur compounds in Syrian asphalt oils; it is cited by W. C. DAY in *J. Frank. Inst.*, **140** (1895), 221.

[3] On sulphur in California petroleum, see PECKHAM, *Proc. Am. Phil. Soc.*, **36** (1897), 108. See PECKHAM, *J. Soc. Chem. Ind.*, **16** (1897), 996, on the sulphur content of bitumens.

[4] *Eng. Min. J.*, **73** (1902), 352.

[5] *Chem.-Ztg.*, **26** (1902), 896.

[6] See p. 609 for a consideration of the sulphur compounds in certain petroleums and the methods employed for their removal.

[7] CLARKE, *Bull.* **491,** *U. S. Geol. Survey*, 690–93.

When cast iron is dissolved in a mineral acid, hydrogen is evolved, but along with impurities that were long ago recognized as similar to known hydrocarbons. In 1864, Hahn[1] attempted to determine their exact nature by passing the gases evolved through bromine. Organic bromides were thus formed, corresponding to the olefines from C_2H_4 to C_7H_{14}, the general formula being $C_nH_{2n}Br_2$. In hydrogen evolved from spiegeleisen Hahn found still higher hydrocarbons, up to $C_{16}H_{32}$; these were collected by direct condensation in wash bottles, without the use of bromine.

In 1873, similar results were obtained by Williams,[2] who dissolved spiegeleisen in hydrochloric acid. The gas evolved therefrom was passed through tubes immersed in a freezing mixture and then through bromine. Williams reported that 7,430 grams of iron gave 49 grams of directly condensible hydrocarbons, with 325.5 grams of bromides; and that this result was confirmed by other experiments. However, the exact nature of the hydrocarbons was not ascertained.

In 1874–8, Cloëz[3] studied the products thus obtained. Hydrochloric or sulphuric acid was allowed to act on large quantities of spiegeleisen, and the gas evolved, partly by direct condensation and partly by absorption in bromine, was found to give large yields of bromides, which were separated by fractional distillation and identified. Ferromanganese gave particularly large amounts of hydrocarbons, and a cast manganese, containing 85.4 per cent. of metal, was even attacked by water alone, with evolution of similarly carburized hydrogen. Cloëz stated that he obtained octylene, C_8H_{16}, by direct condensation, and bromheptylene, $C_7H_{13}Br$, and bromoctylene, $C_8H_{15}Br$, from the bromine solution; and later he described the products obtained in dissolving 600 kg. of white cast iron, which gave 640 grams of oily hydrocarbons, 2,780 grams of bromolefines, and 532 grams of paraffins. Seven of the latter hydrocarbons were identified, from $C_{10}H_{22}$ up to $C_{16}H_{34}$; they are identical with those which occur in petroleum. Therefore, according to the investigations of Cloëz, from the carbides contained in cast iron, a mixture of hydrocarbons chemically resembling petroleum can be prepared.

Most of the carbides react with water, yielding hydrocarbons,

[1] *Ann.*, **129** (1864), 57. Hahn refers to the earlier investigations.

[2] *Am. J. Sci.*, (3), **6** (1873), 363.

[3] *Compt. rend.*, **78** (1874), 1565; **85** (1877), 1003; **86** (1878), 1248.

and the production of acetylene, as an illuminating gas, from calcium carbide, has, as is well known, become an important industry. The yield of hydrocarbons from various metallic carbides may be summarized as follows:[1]

The carbides of lithium, sodium, potassium, calcium, strontium, and barium, when treated with water, yield acetylene, C_2H_2. The carbides of aluminum and glucinum give principally methane, CH_4. The carbide of manganese yields a mixture of methane and hydrogen. The carbides of yttrium, lanthanum, cerium, thorium, and uranium give rise to mixtures of acetylene, methane, ethylene, and hydrogen. The cerium, lanthanum, and uranium compounds yield some liquid and solid hydrocarbons. From 4 kg. of uranium carbide Moissan obtained 100 grams of liquid hydrocarbons, consisting largely of olefines, with some members of the acetylene series and some saturated compounds.

Salvadori[2] found that hydrocarbons can be generated by heating a mixture of calcium carbide and ammonium chloride; this observation was confirmed by Brun.[3] Ammonium chloride is one of the salts most commonly found in volcanic emanations, and these observations have a bearing upon the theories of petroleum formation, a matter which will be discussed in the following section.

While acetylene is a common product of such reactions, it is not a constituent of petroleum. However, Sabatier and Senderens[4] have found that when a mixture of hydrogen and acetylene is passed over reduced nickel at a temperature below 180°C., a mixture of paraffin hydrocarbons is formed which resembles Pennsylvania petroleum. Acetylene alone, in presence of nickel,

[1] See Moissan, *Compt. rend.*, **122** (1896), 1462. See also a summary by J. A. Mathews, *J. Am. Chem. Soc.*, **21** (1899), 647. Berthelot (*Compt. rend.*, **132** (1901), 281) has discussed the reactions involved from a thermochemical standpoint.

[2] *Gazz. chim. ital.*, **32** (1902), 496.

[3] *Arch. sci. phys. nat.*, (4), **27** (1909), 113.

Steiger, in the laboratory of the United States Geological Survey, obtained both saturated and unsaturated hydrocarbons by the similar action of ammonium chloride upon the native iron of Ovifak.

[4] *Compt. rend.*, **134** (1903), 1185; see also, Sabatier, *J. Petr.*, **1901**, 67. Similar results to those of Sabatier and Senderens have also been obtained by Kharitchkov (*Westnik shirow. prom.*, **7**, 180), who studied the petroleum thus synthesized.

also yields aromatic hydrocarbons, and a mixture is produced resembling Russian petroleum. It may be mentioned here that Berthelot[1] proved that acetylene, when heated to the temperature at which glass begins to soften, polymerizes into benzene: three molecules of C_2H_2 yield one of C_6H_6. Benzene itself, when heated under suitable conditions, loses hydrogen, and the residues combine to form diphenyl, $C_{12}H_{10}$.

It is clear, then, from the investigations cited, that, from acetylene as a starting point, higher hydrocarbons may be produced. These, again, at high temperatures, mutually react in such a manner that the complexity of the final product may be very great. Furthermore, as first indicated by Berthelot,[2] carbon and hydrogen can unite directly: when the electric arc is formed between carbon terminals in an atmosphere of hydrogen, acetylene is produced. According to Bone and Jerdan,[3] the rate of formation of acetylene in the arc bears a nearly constant ratio to the rates of formation of methane and ethane; at a lower temperature (about 1,200°C.) methane is the sole product of the union, and even by passing hydrogen over charcoal at 1,200°C. methane may be formed. Pring and Hutton demonstrated the formation of acetylene, independently of an electric arc or spark discharge, at about 1,800°C.

Turning now to the organic syntheses of hydrocarbons, we find that it has long been known that the destructive distillation of organic matter, animal or vegetable, under conditions which preclude the free access of air, will produce hydrocarbons and nitrogenous bases. Warren and Storer,[4] as far back as 1865, prepared a lime soap from menhaden (fish) oil, which, on destructive distillation, yielded a mixture of hydrocarbons hardly distinguishable from coal oil.[5] From this mixture they isolated and identified the paraffins pentane, hexane, heptane,

[1] *Ann. chim. phys.*, (4), **12** (1867), 52.

[2] *Idem*, (3), **67** (1863), 64.

[3] *J. Chem. Soc.*, **71** (1897), 41; **79** (1901), 1042. See also PRING and HUTTON, *idem*, **89** (1906), 1591; and BONE and COWARD, *idem*, **93** (1908), 1975; **97** (1910), 1219.

IPATIEW (*J. prakt. Chem.*, **87**, 479) has suggested that in the experiments of BONE and JERDAN the union of carbon and hydrogen was due to the presence of a small amount of water, whereby the carbon was first oxidized.

[4] *Mem. Am. Acad.*, (2), **9** (1865), 177.

[5] Coal oil is oil distilled from bituminous coal. Properly speaking, the term is not synonymous either with petroleum or with illuminating oil produced therefrom.

and octane; the olefines amylene, hexylene, heptylene, octylene, nonylene, decylene, undecylene, and duodecylene; together with benzene, toluene, xylene, and isocumene, members of the aromatic series. A true artificial petroleum had therefore been prepared.

Engler's noteworthy investigations were announced in 1888.[1] This investigator distilled menhaden oil, unsaponified, at a temperature between 320° and 400°, and under a pressure of ten atmospheres. The distillate resembled petroleum, and contained the paraffins from C_5H_{12} up to C_7H_{16}. Later he reported[2] the isolation of normal octane and nonane, with secondary hexane, heptane and octane. In a still later research with Lehmann,[3] he also obtained olefines from C_6H_{12} up to C_9H_{18} and some derivatives of the benzene series. These experiments confirmed the findings of Warren and Storer, but differed from theirs in the direct use of the oil instead of its fatty acids alone. The lime soap of the American chemists contained only the acids of the oil, separated from its glycerine; the entire oil was used by Engler. From his crude product Engler also prepared an illuminating oil, practically indistinguishable from commercial kerosene.[4]

Day[5] conducted similar experimental work, A mixture of fish (fresh herring) and resinous pine wood was distilled from an iron retort, the process being continued to complete carbonization of the residual material. The distillate consisted of a mixture of oil and water, and the oil, upon redistillation, yielded a residue closely resembling gilsonite. When fish alone was distilled, the final product was more like another solid hydrocarbon, elaterite. Wood alone gave a similar oil, with a similar residue on redistillation. Day thus obtained artificial asphalts which resembled the natural substances; like ordinary asphalt, they contained some nitrogen.

Vegetable oils also yield hydrocarbons upon destructive distillation. Sadtler,[6] for example, established this fact in the case

[1] *Ber.*, **21** (1888), 1816. On the organic origin of naphtha, see RAKUZIN, *J. Russ. Phys.-Chem. Soc.*, **37** (1905), 79.

[2] *Ber.*, **22** (1889), 592.

[3] *Idem*, **30** (1897), 2365.

[4] Observations confirmed by REDWOOD ("Petroleum and Its Products," 2d ed., **1**, 259).

[5] *Am. Chem. J.*, **21** (1899), 478.

[6] *Proc. Am. Phil. Soc.*, **36**, 93.

of linseed oil, although he did not determine the exact nature of the product. Engler[1] obtained hydrocarbons by the distillation of colza and olive oils, as well as from fish oil, butter, and beeswax. Marcusson[2] has described an experiment in which pure oleic acid was heated for several hours to 330°C. in a sealed tube; on opening the tube, there was a strong evolution of gas, and in the residue a product was found which closely resembled a petroleum lubricating oil. Lewkowitsch[3] found that the distillation of chaulmoogra oil with zinc dust led to the formation of gaseous products and a crude petroleum.

PETROLOGENESIS[4]

No subject in geochemistry has been more discussed than that of the origin of petroleum, the controversies relative to which have created a voluminous literature.[5] Theory after theory has been advanced, and discussion thereon is still active. The evidence is abundant indeed, although decidedly contradictory, and leads to different conclusions when studied from different aspects. Only the principal points will be considered here.

The divergent views which have been offered on this subject can be considered to be of two types—the *inorganic* and the *organic*, which hypotheses will be taken up separately.

Inorganic Theories.—The early theories connecting the formation of petroleum with volcanic phenomena[6] may be omitted, since they were formulated at a time when essential evidence

[1] *Cong. internat. du petrole*, Paris, **1900**, 20.

[2] *Chem.-Ztg.*, **30** (1906), 789.

[3] *Ber.*, **40** (1907), 4161. Cf. NEUBERG, *Ber.*, **40**, 4477.

[4] Petrologenesis, or naphthogeny, is that subject of bitumenology which treats of the origin of petroleum. Bitumenology is the science which deals with the occurrence, composition, properties, classification, and technology of the various forms of hydrocarbons included under the names of asphaltum, maltha, and petroleum. See Chap. XVIII.

[5] See especially HÖFER'S "Die Geologie, Gewinnung und der Transport des Erdöls," **1909, 2,** 59–142; CAMPBELL, *Econ. Geol.*, **6** (1911), 363–386; and CLARKE, *Bull.* **616**, *U. S. Geol. Survey*.

[6] In 1804, HUMBOLDT wrote that "petroleum is a product of distillation which exists at a great depth and, acting upon the primitive rocks, develops the forces of all volcanic action." See BRUNET, *Bull. soc. géol. France*, **9** (1838), 252; and REVIERE, *Compt. rend.*, **47** (1858), 646; but especially *Cosmos*, **4** (1858), 274.

was not available; they were mere speculations, nothing more. The modern era begins with a memoir by Berthelot, published in 1866.[1]

Berthelot started from the supposition of Daubrée that the depths of the earth contain alkaline metals in the free state. These react, according to Berthelot, with carbon dioxide at high temperatures, giving rise to alkaline carbides (acetylides), which, when acted upon by the vapor of water, liberate acetylene, which possesses a tendency to polymerize and, by condensation, to give rise to the numerous hydrocarbons which, admixed, form petroleum.[2] The defect of the hypothesis, which Berthelot only advanced tentatively, is that there is no evidence to indicate that alkaline metals are present in an uncombined state at any point below the earth's surface. The starting point is a pure assumption, which is more likely to be erroneous than correct.

The suggestion of Byasson,[3] that petroleum might have resulted from the action on iron or its sulphide at a white heat, of steam and carbon dioxide produced by the infiltration of salt water into the earth, has no present value. Next in chronological order is the famous "*carbide theory*" of Dmitri Mendeléeff,[4] proposed in 1877. This theory presupposes the existence of iron carbides within the earth, to which percolating waters gain access, generating hydrocarbons; the vapors of these then escape through fissures, etc., and condense in the upper-lying porous sedimentary rocks. If such carbides exist at reasonable depths below the surface of the earth, the reactions sugggested by Mendeléeff would undoubtedly occur; but the actual existence of metallic carbides in nature remains to be proved.

Mendeléeff's theory has had many adherents. It found support in the investigations of Hahn, Williams, and Cloëz[5] upon the production of hydrocarbons from cast iron; and it was further strengthened by the researches of Moissan, who himself

[1] *Ann. chim. phys.*, (4), **9** (1866), 481.

[2] According to BERTHELOT, steam acting upon the alkaline metals will also liberate hydrogen, which reacts upon the hydrocarbons first produced to form more completely hydrogenized hydrocarbons.

[3] *Compt. rend.*, **73** (1871), 609.

[4] *J. Russ. Phys.-Chem. Soc.*, **9**, 36; *Ber.*, **10** (1877), 229; *J. Chem. Soc.*, **36**, 283. See also MENDELÉEFF'S "Principles of Chemistry," Eng. trans., **1** (1891), 364–366.

[5] *Compt. rend.*, **75**, 1003.

adopted it,[1] and also suggested that volcanic explosions may perhaps be caused by the action of water upon subterranean carbides. Moissan admitted, however, that some petroleums are possibly of organic origin. The occurrence of methane in volcanic emanations has been cited in support of Moissan's suppositions, although this well-recognized fact may be interpreted otherwise. It may be mentioned in this connection that Silvestri[2] found in basaltic lavas from near Etna both liquid oils and a solid paraffin which melted at 56°, and Brun[3] has made similar observations in his study of Javanese volcanoes. Brun ascribes a volcanic origin to the petroleum of Java; but these oils, as well as the methane, may conceivably have been formed, as Clarke has pointed out,[4] either through a direct union of carbon and hydrogen or from material distilled by volcanic heat out of adjacent sedimentary rocks. The same considerations apply equally well to the petroleum field near Tampico, Mexico, as described by Ordonez,[5] which is cited by Coste[6] in support of his argument in favor of the inorganic origin of petroleum. In the Tampico field the oil rises close to volcanic cones; which, however, have been forced up through a great thickness of Cretaceous shales. The possibility of a distillation of oil from organic matter in the sediments should here be considered (Clarke).

Becker[7] has pointed out that if petroleum is derived from iron carbides, as is assumed in the Mendeléeff theory, there should be magnetic irregularities in petroliferous regions. This he finds to be the case in the Appalachian oil field, where the lines of magnetic declination are sensibly deflected. Similar irregularities appear in the oil fields of California, and magnetic disturbances have also been noted in the region of the Caucasus. While

[1] *Compt. rend.*, **122** (1896), 1462. See also Meunier, *idem*, **123** (1896), 1327.

[2] *Gazz. chim. ital.*, **7** (1877), 1; **12** (1882), 9.

[3] *Arch. sci. phys. nat.*, (4), **27** (1909), 113.

[4] "Data of Geochemistry," 2d ed., 694.

[5] *Min. Sci. Press*, **95** (1907), 249.

[6] *J. Can. Min. Inst.*, **12** (1909), 273. For earlier papers by Coste, see the same journal, **6**, (1903), 73, and *Trans. Am. Inst. Min. Eng.*, **35** (1905), 288. Rigand (*Rev. univ. des mines*, (4), **31** (1910), 145) has also argued in favor of the inorganic origin of petroleum.

[7] *Bull. U. S. Geol. Survey*, No. **401, 1909.** Mohr (*Petroleum*, **6**, 2069) comments favorably upon the proposition set forth by Becker.

these observations are not absolutely conclusive, they are indeed compatible with the "carbide theory."

Several other inorganic theories of the genesis of petroleum may be mentioned. The "*cosmic theory*" of Sokolov,[1] advanced in 1890, considers petroleum to be an original product of the combination of carbon and hydrogen in the cosmic mass; that is, it was formed initially during the consolidation of the planet, became enclosed within the primeval fluid magma, and then separated slowly as it cooled down. In support of his theory, Sokolov cites the occasional discovery of hydrocarbons in meteorites.[2]

Another theory is that of Ross,[3] who endeavored to show that petroleum is a product of the action of solfataric gases upon limestones. Ross partly based his theory on the observation that sulphur has been obtained in laboratory experiments by the action of hot volcanic gases upon chalk, and he assumed that such action would further produce both olefines and paraffins, with a separation of sulphur and a conversion of the calcium carbonate into gypsum. However, these views have not been verified by any experimental evidence.

As has been mentioned, in the preceding section of this chapter, Sabatier and Senderens were able with a mixture of acetylene and hydrogen, by the intervention of finely divided nickel and similar metals, according as the operation was conducted, to obtain liquids resembling the petroleum of Caucasus or that of Galicia, or to produce aromatic hydrocarbons. A mixture of acetylene and hydrogen in excess passing over fine metallic nickel at a temperature below 1800° furnished only petroleum like that of Western Pennsylvania. From this synthesis an explanation of the formation of the different naturally occurring petroleums has been deduced by De Wilde.[4] It suffices to admit, he states,

[1] *Bull. Soc. imp. nat. Moscou*, **3** (1890), 720.

[2] See Wöhler, *Ann.*, **109** (1859), 349, on carbon compounds in the meteorite of Kaba, Hungary. Also Meunier, *Compt. rend.*, **109** (1889), 976, on the meteorite of Mighei, Russia. Nordenskiöld (*Pogg. Ann.*, **141** (1870), 205) found carbonaceous matter in the meteorite of Hessle, Sweden; and Tschermak (*Sitzungsb. Akad. Wien*, **62**, Abth. 2, 1870, 855) reports 0.85 per cent. of a hydrocarbon in the stone which fell at Goalpara, India. The well-known meteors of Orgueil, France, and Cold Bokkeveld, South Africa, were largely carbonaceous. On Orgeuil, see Cloëz, *Compt. rend.*, **59** (1864), 37. Graphite and amorphous carbon are common in meteorites, and in some falls diamonds have been found.

[3] *Rept. Brit. Assn.*, **1891,** 639; *Chem. News*, **64** (1891), 14 and 215.

[4] *Mon. sci. du Quesneville*, May, **1907,** 301–7.

that in the depths of the earth there are found differently distributed alkaline and alkaline-earth metals, as well as the carbides of these metals. Water coming into contact with the first liberates hydrogen, and into contact with the carbides, acetylene. The two gases in variable proportions encounter the metals nickel, cobalt and iron, in a divided state, greatly diffused through nature, and give rise to the reactions mentioned above, which, according to the mode of action, furnish the different known petroleums.

The inorganic theories of the origin of petroleum relate not only to its proximate genesis, but even to fundamental questions of cosmology. Sokolov's hypothesis is an illustration of this, and the assumption of carbides within the earth (Mendeléeff; De Wilde) represents an effort in the same direction. Another indication of this fact is to be found in a memoir by Lenicque.[1] If the molten globe possessed at any time a temperature like that of the electric furnace, carbides, silicides, nitrides, etc., would be among the first compounds to form, and oxidation could not commence until later. Under such conditions some carbides might remain unoxidized through many geologic ages, to be reached by percolating waters at the present time. The development of hydrocarbons would then inevitably follow, although to what extent they might be subsequently consumed is beyond statement. To quote Clarke:[2] "The theory is plausible, but is it capable of proof? Furthermore, does it account for any accumulations of petroleum such as yield the commercial oils of to-day? These essential questions are too often overlooked, and yet they are the main points at issue. We may admit that hydrocarbons are formed within volcanoes, but the quantities definitely traceable to such a source are altogether insignificant. Bitumens occur in small amounts in many igneous rocks, but never in large volume. They are, moreover, absent, at least in significant proportions, from the Archean, and first appear abundantly in Paleozoic time. From the Silurian upward they are plentiful, and commonly remote from great indications of volcanic activity. Even such an occurrence as that of the Pitch Lake in Trinidad, where asphalt is associated with thermal waters, does not necessarily imply a community of origin. It is at least conceivable that the solfataric

[1] *Mem. Soc. ingén. civils, France*, October, **1903**, 346.
[2] *Loc. cit.*, 696.

springs may have acted upon sedimentary accumulations of oil, partly by vaporizing the latter and so bringing it to the surface, and partly by effecting, with the aid of steam and sulphur, the condensations or polymerizations that are observed. These considerations serve to show the need of great caution in dealing with this class of problems and to warn us against hasty generalizations. Speculations based upon individual occurrences of petroleum are of very little value. The entire field, in all of its complexity, must be taken into account."

A new hypothesis of the origin of petroleum has recently been published by Kizhner.[1] It is based upon the experiments of Forquignon,[2] which showed that when hydrogen is passed over red-hot cast iron the carbon in the latter is converted into hydrocarbons, while the traces of sulphur, phosphorus and arsenic are changed to organic compounds of these elements. These experiments also showed that the passage of nitrogen over red-hot cast iron yields cyanogen. The hypothesis assumes that naphtha owes its origin to the interaction of the hydrogen with the carbon, both of which are held in solution by the iron existing in the bowels of the earth. This interaction began when, in the process of cooling, the earth reached the state of a red star. The difficultly fusible iron and carbon liquefied and solidified first, and, owing to its high specific gravity, the iron, holding in solution the hydrogen, settled at the lower strata of the globe. Owing to the high temperature prevailing in the depths of the earth, the reaction between the hydrogen and the carbon has been going on for ages and is doubtless going on now. The comparatively low specific gravity of the hydrocarbons causes them to rise as naphtha to the surface, passing through various strata which modify its character. The cyclic hydrocarbons of naphtha owe their formation to the high temperature and pressure prevailing in the innermost strata. As to the optical activity of naphtha, it is due to the influence of terrestrial magnetism on the different degrees of reactivity (decomposition, condensation, oxidation, etc.) of optical antipodes, it being assumed that these differ in reactivity to such a slight extent that the difference escapes our observation. Hence in the usual reactions racemic compounds are formed. But the magnetism of the earth enhancing the reactivity of both antipodes and acting through geologic ages,

[1] *J. Russ. Phys.-Chem. Soc.*, **46**, 1428.

[2] *Ann. chim. phys.*, (5), **23**, 516.

may favor the reactivity of one of them, changing it to other substances, and thus permitting the other antipode to impart activity to the naphtha.

While methane is sometimes formed as a volcanic emanation, it is more commonly of organic origin and is generally produced in small amounts. Gas in Iowa wells has been described[1] which occurs in the drift and is apparently of vegetable origin, since buried vegetation alone can account for its formation under the reported conditions.

Hoppe-Seyler[2] and Tappeiner[3] have shown that methane may be artificially produced by the fermentation of cellulose, together with carbon dioxide and free hydrogen. During the decay of seaweeds, however, according to Phillips,[4] the generated gases consist largely of carbon dioxide, hydrogen, and nitrogen. The apparatus in which the experiment was performed was allowed to stand in position for two and a half years, and during that time, following the first rapid evolution of gas, a very slow, continuous production was observed. At the end of the period, the gas consisted of methane. Phillips concluded, from this evidence, that buried vegetable matter, after a brief era of rapid gas evolution, may pass into a condition of extremely slow decay when methane is generated. Perhaps methane is not the only hydrocarbon thus produced.

In several cases, as in the Placereta Canon field of Los Angeles County, California, the Thrall field in Texas, in several seepages in Mexico, and in traces elsewhere, petroleum exists in igneous rock and might appear to add confirmation to an inorganic origin, were it not that the number of cases where it occurs in sedimentary deposits are so much greater. Many associations of petroleum with basaltic rock, subterranean salt, sulphur and gypsum masses, and with hot water, in Mexico, the southern United States, Hungary and Rumania, might also appear to confirm an inorganic theory, but nothing conclusive has ever been discovered which would apply to all or to a majority of cases.

[1] See Leonard, *Proc. Iowa Acad. Sci.*, **4**, 41. Witter (*Am. Geol.*, **9** (1892), 319) has described a gas well, about 100 ft. deep, near Letts, Iowa.

[2] *Ber.*, **16** (1883), 122.

[3] *Ibid.*, 1734, 1740. See also Popov, abstract in *J. Chem. Soc.*, **28** (1875), 1209, on gas from river mud near sewer openings.

[4] *Am. Chem. J.*, **16** (1894), 427. Phillips supports the view that petroleum has been formed by the slow decay of marine vegetable matter, under water, in the absence of air.

Organic Theories.—Sufficient evidence has been presented above and especially in the preceding section of this chapter to show that hydrocarbons analogous to natural gas and petroleum may be derived either from animal or vegetable matter, or both. This is conceded, although argument and speculation relative to the genesis of the larger accumulations of mineral oil, is abundant. It may be said, however, that the investigations of Engler have induced a quite general adherency to the belief in the *animal origin of petroleum*, although the details of the transformation process are variously interpreted.[1]

Theories of Animal Origin.—Engler ascribes the derivation of petroleum from animal remains to a putrefaction process, which eliminates the nitrogen compounds. The residual fats are then converted by heat and pressure[2] into hydrocarbons whose boiling points lie below 300°, and these later undergo a partial autopolymerization into denser forms.[3] There is con-

[1] For a very complete summary of all the hypotheses relative to the formation of petroleum, see HÖFER, "Das Erdöl," **1906**, 160–229. See also REDWOOD, "Petroleum," **1** (1913), 268–283. Other summaries are by AISINMANN, *Z. angew. Chem.*, **1893**, 739; *idem*, **1894**, 122; KLEMENT, *Bull Soc. belge geol.*, **11**, proc. verb., **1897**, 76. Recent memoirs on the subject are by DE WILDE, *Arch. sci. phys. nat.*, (4), **23** (1907), 559; NEUBERG, *Sitzungsb. K. preuss. Akad.*, May 16, **1907**; and CHAUTARD, *Bull soc. de l'ind. min.*, July, **1915**.

[2] *Ber.*, **30** (1897), 2358. For more recent articles by ENGLER, see *Z. angew. Chem.*, **21** (1908), 1585; *Verhandl. naturwiss. Vereins Karlsruhe*, 1908, **20**, 65; and *Compt. rend. Cong. internat. pétrole, Bucarest*, 1910, **2**, 1.

[3] The theory of animal origin, now usually connected with the names of HÖFER and ENGLER, traces back to the Frenchman HAGUET in 1704. As stated by ENGLER, it is that natural fatty bodies (both vegetable and animal) and fatty bodies artificially obtained, as the fatty acids, when distilled under a pressure of 20 to 25 atmospheres at 360° to 420°, yield a mixture of hydrocarbons resembling petroleum and without carbonaceous residue. In distilling a fish oil in this way, the hydrocarbons obtained appeared to be about three-fourths saturated hydrocarbons and one-fourth olefines; of "naphthenes" and aromatic hydrocarbons there appeared to be only traces formed. Small quantities of gases like CH_4, CO, CO_2 and C_2H_4 and from 1 to 2 per cent. of water were also formed. The cadavers of terrestrial and marine animals, if submitted to the same distillation under pressure, yield a distillate without carbonaceous residue; but the distillate contains, besides the hydrocarbons, a notable quantity of amines and pyridine bases, due to the decomposition of albuminoid material. Engler notes that the cadavers of fish, etc., rapidly lose their nitrogenous material by putrefaction, while the fatty bodies resist decomposition and only slowly undergo the changes resulting in the formation of the petroleum-like bodies. This disappearance

siderable doubt as to the actual possibility of such a polymerization. Mabery[1] reasonably maintains that the changes are always in the opposite direction: the more complex hydrocarbons formed first partially break down subsequently into lower members of the series. Marcusson[2] also shares this view. The removal of the nitrogenous substances by any putrefaction process is also open to doubt; certainly it is not universal. The nitrogen bases of California petroleum supply perhaps the strongest evidence that the proteids contribute their share to the make-up of petroleum, and indicate that these particular oils are of animal origin.

Evidence in support of the derivation of petroleum from fish remains has been contributed by several investigators. For instance, Dieulafait[3] reported that while the copper shales of Mansfeld are strongly impregnated with bitumen, they are also rich in fossil fish. Then, too, Galician petroleum is invariably associated with menilitic schists in which fish remains are abundant. Szajnocha has computed[4] that the annual catch of herring on the north coast of Germany would, if its fats were half converted into petroleum, yield in 2560 years as much oil as Galicia has produced. Bertels,[5] however, considers that the Caucasian petroleums result from the decomposition of mollusks.[6]

The views of Engler have received special attention because of their experimental basis, for he was not the original advocate of animal derivation. For example, Ochsenius[7] has endeavored to connect the formation of petroleum with that of the mother-

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of animal tissue and persistence of the fatty bodies under the name of adipoceres (mixtures of free fatty acids) has long been known and was referred to by Liebig.

[1] *J. Am. Chem. Soc.*, **28** (1906), 429.

[2] *Chem.-Ztg.*, **30** (1906), 788.

[3] Cited by Jaccard, *Arch. sci. phys. nat.*, (3), **24** (1890), 106.

[4] *Ber.*, **33** (1900), 16. See also *Cong. internat. du pétrole*, **1900**, 30. Cf. De Wilde, *Mon. sci. du Quesneville*, May, **1907**.

[5] Cited by Höfer "Das Erdöl," **1906**, 219. Hornung (*Z. Deutsch. geol. Gesell.*, **57**, *Monatsber.*, **1905**, 534) argues in favor of fishes as the raw material of petroleum. See also Jahn, *Jahrb. K.-k. geol. Reichsanstalt*, **42** (1892), 361. For arguments against the theory of Engler, see Pantanelli, *Bull. Soc. geol. ital.*, **25** (1906), 795; Pantanelli seems to favor the inorganic origin of petroleum.

[6] In the Kuban district, the oil, accompanied by salt water, exudes directly from beds of molluscan remains, which occur in enormous quantities.

[7] *Chem.-Ztg.*, **15** (1891), 935; and *Z. Deutsch. geol. Gesell.*, **48** (1896), 239.

liquor salts which accumulate during the last stage of the evaporation of sea water; Mrazec[1] has noted this association of salt and oil in the case of Rumanian petroleum; and Heusler,[2] indorsing Engler's principal conclusions, like Ochsenius, who mentioned magnesium chloride as the active substance, invoked the aid of another agent in producing a polymerization of the hydrocarbons (aluminum chloride). It has not been experimentally demonstrated that hydrolyzed water solutions of aluminum chloride are effective; moreover, aluminum chloride does not occur in any notable quantity in natural waters.[3]

Zaloziecki[4] has suggested that the salts probably retard and modify the decay of animal matter on or near the seashore, and in this way provide for the gradual transformation into petroleum.[5] It is of interest to note that the brines which are frequently associated with petroleum generally possess a composition indicative of a marine origin and do not resemble solfataric or volcanic waters.[6] Furthermore, Mendeléeff's objection to the possibility of petroleum forming at the bottom of the sea—

[1] *Compt. rend. Cong. internat. pétrole, Bucarest,* 1910, **2,** 80. Also "L'industrie du pétrole en Roumanie," Bucarest, **1910.** The presence of methane, ethane, etc., in rock salt has been studied by COSTĂCHESCŬ, *Ann. sci. Univ. Jassy,* **4** (1906), 3. On the animal origin of petroleum, see also SINGER, *Inaug. Diss.,* Zurich, **1893.**

[2] *Z. angew. Chem.,* **1896,** 288, 318.

[3] A possible exception to this statement is cited by OCHSENIUS (*Z. Deutsch. geol. Ges.,* **48** (1896), 239), who mentions a water containing, in its solid residue, 23.91 per cent. of aluminum chloride. This water accompanied a petroleum.

[4] *Chem.-Ztg.,* **15** (1891), 1203.

[5] The latter process is not necessarily very slow, for SICKENBERGER (*ibid.,* 1582) has shown that in small bays of the Red Sea, where the salinity reaches 7.3 per cent., petroleum is actually forming as a scum upon the surface of the water. Living forms are abundant in these bays, and their remains, after death, furnish the hydrocarbons. The latter are to some extent absorbed into the pores of coral reefs, and so contribute to the formation of bituminous limestones. FRAAS (*Bull. Soc. sci. nat. Neuchâtel,* **8** (1868), 58) supplied data of similar purport. He found in Egypt shells filled with bitumen, and noticed that the bituminous beds were rich in fossils, while the nonbituminous strata were poor. In the region of the Dead Sea, also, FRAAS noticed that bitumen was abundant in beds of baculites, from which it exudes to accumulate upon the shore.

[6] The waters accompanying the naphtha of the Grosny district, Russia, as analyzed recently by KHARITCHKOV (*Chem.-Ztg.,* **1907,** 295), appear to be exceptional. In these sodium carbonate is more abundant than the chloride, and salts of ammonium and the amines are also present.

namely, that being lighter than water it would float away and be dissipated—is negatived by the well-known fact that mud and clay are capable of retaining oily matters mechanically.[1]

Höfer mentions the following as arguments in favor of an *animal origin* for petroleum:

1. Oil is found in strata containing animal but little or no plant remains. This is the case in the Carpathians and in the limestone examined in Canada and the United States by Hunt.

2. The shales from which oil and paraffin were obtained in the Liassic oil-shales of Swabia and of Steierdorf in the Banat, contained animal but no vegetable remains.. Other shales, as, for instance, the copper-shales of Mansfeld, where the bitumen amounts to 22 per cent., are rich in animal remains and practically free from vegetable remains.

3. Rocks which are rich in vegetable remains are generally not bituminous.

4. Substances resembling petroleum are produced by the decomposition of animal remains.

5. Fraas observed exudations of petroleum from a coral reef on the shores of the Red Sea, where it could only be of animal origin.

In summing up the evidence as to origin, Höfer expresses the belief that petroleum is of animal origin and has been formed without the action of excessive heat, and observes that it is found in all strata in which animal remains have been discovered. He considers that the oil is the primary, and natural gas a secondary, product.

Orton's opinions, which are somewhat different, are as follows:

1. Petroleum is derived from organic matter.

2. Petroleum of the Pennsylvania type is derived from the organic matter of bituminous shales and is probably of vegetable origin.

3. Petroleum of the Canada type is derived from limestones and is probably of animal origin.

4. Petroleum has been produced at normal rock temperatures

[1] The littoral sediments probably aid in the process of petroleum formation, as Clarke has pointed out, if only to the extent of retaining the fatty substances from which the oil is to be produced. The opinion has been expressed that the beds of sulphur which occur adjacent to some oil wells, notably in Texas, were probably formed by the reducing action of organic matter upon sulphates, such as gypsum, a mineral which is often associated with marine deposits and with petroleum.

(in American fields) and is not a product of destructive distillation of bituminous shales.

5. The stock of petroleums in the rocks is already practically complete.

The Engler-Höfer theory, as developed by its authors up to the present time, states that petroleum is derived from the natural decomposition *in situ* of the fatty remains of marine organisms, both animal and vegetable.

Engler thus enumerates the various stages which, in his opinion, occur in the formation of petroleum from organic matter:

1. Putrefaction, or fermentation, by which albumen and cellulose, etc., are eliminated. Fatty matters (and waxes), with a small quantity of other durable material and possibly fatty acids from the albumen, remain.

2. Occurs partly during the first stage: saponification of the glycerides, and production of free fatty acids, either from action of water or ferments, possibly both. The waxy esters are either wholly or partly hydrolyzed. The residues from many crude oils are probably due to lack of completion of these actions.

3. Carbon dioxide is eliminated from the acids and esters, water from the alcohols, oxy-acids, etc., leaving hydrocarbons of high molecular weight containing oxy-compounds. Comparable with these is the intermediate product, like ozokerite, of Krämer and of Zaloziecki, who also regarded ozokerite as representing an early stage in the formation of petroleum.

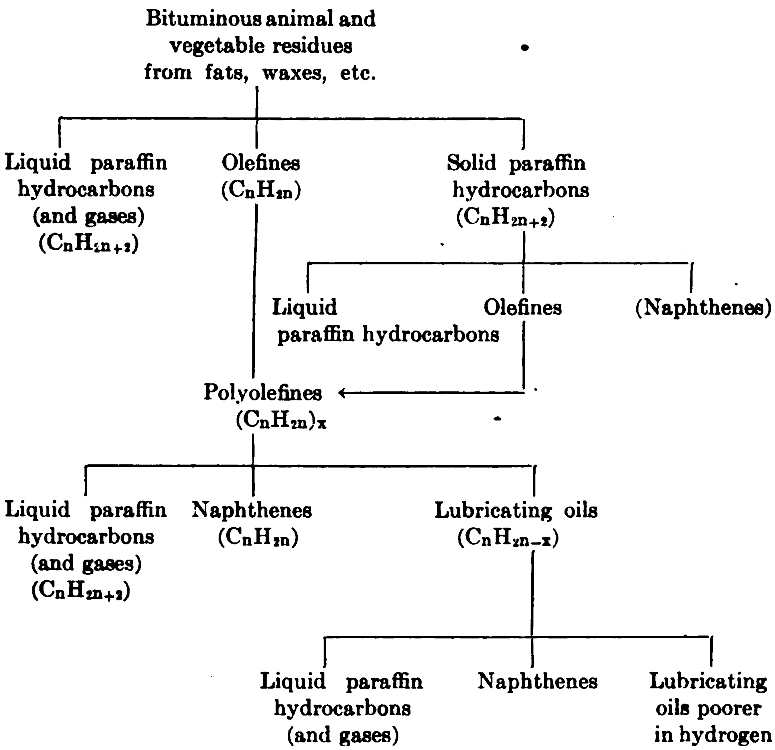
4. Formation of liquid hydrocarbons and violent reaction, with "cracking," into light or gaseous products (formation of proto-petroleum).

He adds, in regard to all these stages, that he is assuming that time and temperature compensate one another, though pressure has no action beyond raising the temperature slightly and is in no way equivalent to it. He considers that with moderate temperatures and pressures oil of intermediate grade will be formed, while increase of either tends to form light oils. Polymerization and addition-products are formed after the completion of stage 4.[1]

Engler further suggests that the various hydrocarbons are formed as under:

[1] On the formation of the chief constituents of petroleum, see ENGLER, *Petroleum*, **7** (1912), 399.

SCHEME SUGGESTED BY ENGLER AS REPRESENTING THE PROCESSES OCCURRING IN THE FORMATION OF PETROLEUM



Methane Series Hydrocarbons—as direct products from the "bitumen," *i.e.*, the fats of stage 1 and heavy hydrocarbons of stage 3.

Olefines—directly formed, by splitting up of saturated chain hydrocarbons of the paraffin series,

$$C_{2n}H_{4n+2} = C_nH_{2n+2} + C_nH_{2n};$$

they would afterward polymerize to form simple methanes, etc., but they are probably partly re-formed in distillation, especially at high temperatures, as in the "cracking" process.

"Naphthenes"—perhaps from the decomposition of aromatic acids or esters, or from isomeric olefines under the influence of heat and pressure.

Benzenes, etc.—from the decomposition of fats at comparatively high temperatures.

Theories of Vegetable Origin.—The similarity between petroleum and the oils obtained by the destructive distillation of peat, lignite, coal and oil-shale, led to an early belief that petroleum was produced from one or all of these materials.[1] It is true that this theory was soon abandoned in its original form, but a few later writers have also maintained that terrestrial vegetation has in some cases undergone a mineralization, being converted into liquid and gaseous hydrocarbons instead of the usual solid lignites and coal.[2]

Lesquereux[3] argued in favor of the derivation of the Devonian oils of the eastern United States from cellular marine plants, especially fucoids, the remains of which are plentiful in the petroliferous formations. This hypothesis induced Vouga[4] to make the suggestion that great masses of fucus, like those of the Sargasso Sea, might sink to the bottom of the ocean, and there, decomposing under pressure, yield petroleum. Redwood states

[1] See HATCHETT, *Trans. Linn. Soc.*, **4** (1798), 129; *Phil. Trans.*, **1804**, 385.

[2] See, especially, WALL, *Quart. J. Geol. Soc.*, **16** (1860), 467; SMITH, *J. Soc. Chem. Ind.*, **1891**, 979; and SADTLER, *Am. J. Pharm.*, **68** (1896), 465.

During the past century it was commonly supposed that oil originally had been distilled by nature from beds of coal into contiguous formations. It is interesting to note that such a supposition has been world-wide—even the Chinese having the term "May-yu," indicating some impression that oil is related to coal. Nevertheless, the evidence is strong that there has been little or no connection between the two; and moreover that oil exists in some localities hundreds of miles from the nearest coal deposit.

[3] *Bull. Soc. sci. nat. Neuchâtel*, **7** (1866), 234.

[4] See discussion following LESQUEREUX's communication.

that the salt marshes of Sardinia are covered from time to time with sheets of seaweed, decomposing into an oily substance resembling petroleum;[1] and that petroleum is being formed at the present time on the shores of the Sound near Lund, Sweden, by the decomposition of seaweed in sand.[2] Watts[3] observed that the saline waters occurring along with petroleum in the central valley of California are unusually rich in iodine and connected this iodine with the occurrence of iodine in seaweed, which he regards as a probable source of this petroleum.

Additional evidence is had from the investigations of Bertrand and Renault,[4] who have shown that Boghead mineral, torbanite, and kerosene shale, which yield crude oils resembling certain petroleums upon distillation, are derived from gelatinous algae, whose remains are embedded in what was once a brown, humous jelly. Newberry[5] and Peckham[6] regard the liquid petroleums as natural distillates from carbonaceous deposits, which were laid down at depths below the horizons where the oil is now found. The heat generated during metamorphism is supposed to be the dynamic agent in this process, although many productive regions present no evidence that any violent metamorphoses have ever occurred.[7]

Binney and Talbot[8] described a peculiar occurrence of petroleum in a peat bed on Down Holland Moss, not far from Liverpool, England. The origin of this oil was attributed by Binney to the decomposition of the peat itself, but this mode of genesis

[1] "Petroleum," 3d ed., **1**, 132.

[2] *Idem*, 148. Cf., however, 198, on the occurrence of petroleum in traces in thermal springs at Koumac, New Caledonia.

[3] *Bull. California State Mining Bur.*, No. **19**, 202. See also *Bull.* No. **3** for more details. In *Bull.* No. **16**, 1899, Cooper discusses at length the genesis of petroleum and asphalt in California. *Bull.* Nos. **31** and **32** also relate to this subject. See also Prutzman, *Calif. Derrick*, **3**, Nos. 1–6.

[4] *Compt. rend.*, **117** (1893), 593. See also Bertrand, *Compt. rend.* VIII. *Cong. géol. internat.*, **1900**, 458. According to Jeffrey (*Proc. Am. Acad.*, **46** (1910), 273), the supposed gelatinous algæ are the spores of vascular cryptogams.

[5] "Geology of Ohio," **1** (1873), 158. See also an earlier paper by Newberry, "Rock Oils of Ohio," in *Fourteenth Ann. Rept. Ohio State Board Agr.*, **1859**, 605.

[6] *Proc. Am. Phil. Soc.*, **10** (1868), 445; **37** (1898), 108.

[7] Stremme (*Centralbl. Min., Geol. u. Pal.*, **1908**, 271) has shown that the polymerization of petroleum may itself generate heat.

[8] *Trans. Manchester Geol. Soc.*, **8** (1868), 41; **3** (1860), 9. See also Binney, *Proc. Manchester Lit. Phil. Soc.*, **3**, 136.

has been doubted.[1] However, it is reported by Newberry[2] that in the Bay of Marquette, where the shore consists of peat overlying Archean rocks, bubbles of methane arise, together with drops which cover the surface of the water, in spots, with an oily film.

In 1899, Stahl[3] and, independently, Krämer and Spilker[4] called attention to a possible derivation of petroleum from Bacillariaceæ (diatoms), which occur largely in peat. Diatoms contain drops of oily matter distributed in the plasma, and from diatomaceous peat 1.5 to 4 per cent. of a wax resembling ozokerite can be extracted.[5] The following theory of the origin of petroleum has been developed by Krämer and Spilker:

Lakes became filled up in the process of time with a growth of diatoms; over this growth other deposits were formed subsequently. The decay of the diatoms (which takes place very slowly) gave rise to ammonium carbonate, which hydrolyzed the wax present; from the resulting acids, carbon dioxide and monoxide and water were eliminated, and ozokerite formed. Where the pressure was small and the temperature low, this was converted further into a comparatively low boiling petroleum; under greater pressure and higher temperature, the sulphur present also exerting an influence, a petroleum was formed which contained a large proportion of viscid, high-boiling substances (probably formed by polymerization of olefines); more extended action of the sulphur, and of atmospheric oxygen, gave rise to a petroleum containing much asphalt. Generally speaking, the petroleum would be absorbed by a calcareous bed, a deposit of asphalt being thus formed.[6]

Krämer and Spilker's theory has not been received with very general acceptance, but it undoubtedly contains elements of importance. Potonié's hypotheses[7] seem to be an extension of Krämer and Spilker's. Potonié calls attention to the "faulschlamm" or "sapropel," a slime rich in organic matter, which is formed from gelatinous algæ and accumulates at the bottom of

[1] Höfer ("Das Erdöl," 110) states that this deposit lies upon sand which may have supplied the bitumen.

[2] *Annals N. Y. Acad. Sci.*, **2** (1882), 277.

[3] *Chem.-Ztg.*, **23** (1899), 144; **30** (1906), 18.

[4] *Ber.*, **32** (1899), 2940; **35** (1902), 1212. Cf. Engler, *idem*, **33** (1900), 7.

[5] See also Guignet, *Compt. rend.*, **91** (1880), 888, on wax from peat.

[6] Cf. Kharitchkov, *J. Russ. Phys.-Chem. Soc.*, **44** (1912), 354.

[7] *Natur. Wochenschr.*, **20** (1905), 599.

stagnant waters. Such a slime, Potonié believes, may be the parent substance from which bitumen, by a process of decay, was probably derived.[1]

Comments on the oceanic sediments[2] suggest an intermediate group of theories, which assume a mixed origin for petroleum. Animal matter in some cases, vegetable matter in others, or both together, are supposed to be the primary source of supply. Jaccard,[3] for example, maintains that the liquid oils are derived from marine plants, while the viscous or solid bitumens may originate from mollusks, radiates, etc. Some oils, again, are supposed to be of mixed origin, and it would seem probable that the last class is the most common. Similar views have been advanced with reference to American petroleum—that of Pennsylvania being attributed to marine vegetation, that of California to animal remains; in fact, the American literature of petroleum contains numerous suggestions of this order.[4]

The fact that some petroleums are optically active is, accord-

[1] In this connection, and with reference to the adequacy of the proposed source, attention may be directed to the enormous accumulation of radiolarian and globigerina oozes on the bottom of the sea.

[2] These oceanic sediments are especially noticed by Engler in a paper read before the petroleum congress in 1900 (*Cong. internat. du pétrole*, Paris, **1900**, 28). In Thompson's monograph, "The Oil Fields of Russia," London, **1904**, 85–87, a theory is developed to account for the probable formation of bitumens on the sea bottom. Thompson regards fish remains as an important source of supply. Mikhailovski (*Bull. Com. géol. St. Petersburg*, **25** (1908), 319) derives the Caucasian petroleum from marine sediments. Morrey (*Bull. Geol. Survey Ohio*, No. 1, **1903**, 313) suggests that bacteria have been the chief agents in transforming other organic matter into hydrocarbons.

[3] *Eclog. Geol. Helvet.*, **2** (1890), 87. See also *Arch. sci. phys. nat.*, (3), **23** (1890), 501; **24** (1890), 106. Jaccard studied especially the bitumens of the Jura.

[4] In addition to the memoirs already cited, see the *Reports* of the Second Geol. Survey, Pennsylvania. Also Bownocker, *Geol. Survey Ohio*, (4), *Bull.* No. 1, **1903**; Gorby, *Sixteenth Ann. Rept., Indiana Dept. Geol. and Nat. Hist.*, **1888**; Blatchley, *idem*, *Twenty-eighth Ann. Rept.*, **1904**; Haworth, *Kansas Univ. Geol. Survey*, **1** (1896), 232; Brumell, *Geol. Survey Canada, Ann. Rept.* **5**, Q, **1893**; and McGee, *Eleventh Ann. Rept., U. S. Geol. Survey*, pt. 1, **1891**, 589. Harperath (*Bol. Acad. nac. cien. Córdoba* (Argentina), **18** (1905), 153) has published a long memoir on petroleum and salt. Dalton (*Econ. Geol.*, **4** (1909), 603) advocates the organic origin of petroleum.

ing to Walden,[1] of importance in determining the origin of petroleum. Only the oils derived from organic matter, Walden asserts, can possess this property; the hydrocarbons prepared from inorganic materials, such as metallic carbides, being optically inert. The oils distilled from coal, which is of vegetable origin, are active; and petroleum, which has the same peculiarity, is presumably formed from similar materials. The optical activity is attributed by some to derivatives of cholesterin, of animal origin, or else to its vegetable equivalent, phytosterin.[2] The general conclusions are very important and quite convincing in certain respects, but require considerable investigation before they can demand acceptance.

As Clarke reminds us,[3] in any attempt to discover the genesis of petroleum the quantitative adequacy of the proposed sources must be considered. Superficial observations are deceptive; since they seem large, the visible and productive accumulations which furnish the oils of commerce are likely to be overrated. Orton[4] has called attention to the fact that while disseminated petroleum is well-nigh universal, the accumulations thereof are rare. In certain districts the shales and limestones are generally impregnated with traces of bitumens, which seem at first sight to be insignificant, but which really represent enormous quantities. In the Mississippian ("sub-Carboniferous") limestones of Kentucky petroleum is generally present. If it amounts to only 0.10 per cent., each square mile of rock, with a thickness of 500 ft., would yield about 2,500,000 bbl. of oil. Hunt[5] estimates that in the limestone of Chicago, with a thickness of 35 ft., there are

[1] *Chem.-Ztg.*, **30** (1906), 391, 1155, 1168. WALDEN cites many examples of this optical activity. See also ENGLER, *ibid.*, 711. RAKUZIN (*Orig. Com. 8th Intern. Cong. Appl. Chem.*, **25**, 721) regards the optical activity of petroleum as the most important factor in determining the genesis of a crude oil.

[2] See RAKUZIN, *Chem-Ztg.*, **30** (1906), 1041; *Ber.*, **42** (1908), 1211, 1640, 4675; MARCUSSON, *Chem.-Ztg.*, **31** (1907), 419; **32** (1908), 377, 391; ALBRECHT, *Inaug. Diss.*, Karlsruhe, **1907**; UBBELOHDE, *Ber.*, **42** (1909), 3242; **43** (1910), 608. ZALOZIECKI and KLARFELD (*Chem.-Ztg.*, **31** (1907), 1155, 1170) question the cholesterin theory and favor that of POTONIÉ. See also ZALOZIECKI, *Compt. rend. Cong. internat. pétrole, Bucarest,* **1910,** 718; and STEINKOPF and WINTERNITZ, *Chem.-Ztg.*, **38** (1914), 613.

[3] *Loc. cit.*, 703.

[4] *First Ann. Rept., Geol. Survey Ohio,* **1870,** Chap. XI; *Geol. Survey Kentucky*, Report on occurrence of petroleum, etc., **1888–89.**

[5] "Chemical and Geological Essays," **1875,** 168.

7,743,745 bbl. of oil to each square mile of territory. Such data, together with the computations by Szajnocha relative to Galician petroleum, lead to the conviction that the formation of bitumens is a general process and by no means exceptional. Wherever sediments are laid down, inclosing either animal or vegetable matter, there bitumens may be produced. The presence of water, preferably salt, the exclusion of air, and the existence of an impervious protecting stratum of clay, seem to be essential conditions toward rendering the transformation possible. Seaweeds, mollusks, crustaceans, fishes, and even microscopic organisms of many kinds may contribute material to the change. In some cases plants[1] may predominate; in others animal remains; and the character of the hydrocarbons produced is likely to vary accordingly, just as petroleum varies in different fields.

The question, sometimes raised, as to how petroleum becomes concentrated, will not be discussed here.[2] Probably circulating waters have much to do with the process, but whatever that may be the laws governing the motion of liquids must inevitably rule.

General Conclusions.—In conclusion, it may be said that nearly all of the proposed theories to account for the origin of petroleum include certain elements of truth; in regard to some of the theories, considerable experimental proof has been forthcoming. *Sokolov's cosmic hypothesis* is sustained by the fact that hydrocarbons are found in meteorites. The *volcanic hypothesis* is supported by the fact that hydrocarbons occur among volcanic emanations. The *organic origin of petroleum*, however, seems to be best maintained by the geologic relations of the hydrocarbons. On the whole, the *Engler-Höfer dual theory*[3] has the largest number of adherents, to whom the evi-

[1] See Breger, *Min. World*, **35**, 1219, 1321, for a full consideration of the vegetable derivation. Mabery (*J. Ind. Eng. Chem.*, **6** (1914), 106) has concluded that the origin of petroleum in certain American fields must be looked for chiefly in the decay of vegetation.

[2] For a discussion of this problem, see Höfer, "Das Erdöl," **1906**, 223. Also Adams, *Trans. Am. Inst. Min. Eng.*, **33** (1903), 340; and Day, *ibid.*, 1053. Orton's reports, previously cited, contain important contributions on this subject.

[3] See Engler and Höfer's "Das Erdöl," 1909, **2**, 59–142; Aisinmann, *Z. angew. Chem.*, **1893**, 738; **1894**, 122; Ipatiew, *J. prakt. Chem.*, **84** (1911), 800; and Hirschi, *Petroleum*, **7**, 62.

dence seems to be clear that no important petroleum field derived its hydrocarbons from purely inorganic sources.[1] Campbell, who has considered the available evidence in a searching manner,[2] states that this testimony favors the *animal origin* of most petroleum, although a certain amount has probably been derived from the fatty portions of plants. Some authorities contend that oils having an asphalt base are derived from animal matter and oils having a paraffin base from vegetable matters. Still other adherents of the organic theories claim that the differences in quality of the oils are due to differences of capillarity, heat, pressure, extent of migration, etc., but none of these theories seems to have been proved. Richardson has recently expressed the opinion that the phenomena of surfaces and films, as demonstrated by the recent developments of colloidal chemistry, open up an entirely new point of view for the interpretation of the origin of petroleum and asphalt and one which will be, no doubt,

[1] DAVID WHITE (*J. Wash. Acad.*, 5, 189) has considered the ingredient materials of coals and oil rocks, the biochemical and dynamo-chemical processes of alteration of the organic detritus, its devolatilization, its regional alteration and the corresponding regional differences in petroleums, and the occurrence of higher rank oils in regions of greater alteration of the carbonaceous residues. His conclusions are as follows: (1) Petroleum is a product generated in the course of the geodynamic alteration of deposits of organic débris of certain types buried in the sedimentary strata. (2) The quantity and characters of the oils generated are determined by: (*a*) the composition of the organic deposit at the beginning of alteration; (*b*) the stage in the progress of this; (*c*) the elimination of the heavier and more viscous hydrocarbons through filtration incident to migration. It is probable that the composition of the mother organic deposit largely regulates the types of oils; it may account for the nitrogen and sulphur content, color, etc. (3) The rank of the oils is proportional to the degree of alteration of the carbonaceous deposits. (4) The change is marked by concentration of hydrogen in the distillates and of carbon in the residues. (5) Abnormally light oils are in most cases due to filtration. (6) In general, the oils found in successive underlying formations are progressively higher in rank. (7) In regions where the progressive devolatilization of the organic deposits in any formation has passed a certain point (usually 65–70 per cent. fixed carbon) commercial oil pools are not present in that or underlying formations although gas may occur. (8) Wherever the regional alteration of the carbonaceous residues passes the point marked by 65–70 per cent. of fixed carbon in the pure coals, the light distillates appear in general to be gases at rock temperatures.

[2] "Petroleum and Natural Gas Resources of Canada," *Canada Dept. of Mines, Mines Branch*, 1914, **1**, 76.

widely developed in the future. It seems to Richardson[1] that the origin of all forms of petroleum must be attributed to surface action between a natural gas and the "sands," using this term in a general sense, with which it comes in contact.

[1] *J. Ind. Eng. Chem.*, **8** (1916), 4.

CHAPTER II

THE GEOLOGY OF PETROLEUM

By Frederick G. Clapp[1]

As shown in the preceding chapter, petrologenesis has been a subject of research and extended theoretical discussion by chemists and geologists for many years, but without arriving at results universally accepted. In any consideration of the geology of petroleum, it is important to first review the question of origin, so far as knowledge allows at the present time; for, to quote Campbell,[2] "much that is now uncertain could be eliminated were the source of the oil known and the mode of its origin understood. The geologist cannot afford to ignore this phase of the question." It is assumed by the author of this chapter that the reader is familiar with the general aspects of petrologenesis.

Surface Indications of Petroleum.—While the evidences of the presence of petroleum which are commonly noted by the geologist or geological engineer are not such as can be seen and comprehended by the average layman, there are, however, in many oil fields, certain more direct indications which have a definite bearing on the existence of oil, either in that particular locality or at a distance. These so-called "surface indications" may be classified as (1) oil seepages or springs, (2) natural gas springs, (3) outcrops of sands impregnated with petroleum or bitumen, (4) bituminous dikes, and (5) bituminous lakes. Any one of these generally has some association with petroleum, but the latter very frequently lies at a great distance from the point where the evidence appears on the surface.

To illustrate, it is a fact that a formation which reaches the surface of the ground at a particular point, and from which the seepages of oil, gas or asphalt are seen to emerge, may incline downward at such an angle that the point of greatest amount

[1] Petroleum Engineer and Managing Geologist, The Associated Geological Engineers, 120 Broadway, New York.

[2] *Econ. Geol.*, 6 (1911), 363.

of oil in it lies many miles from the exposed outcrop.′ For this reason, it is generally inadvisable to drill on or near seepages unless there is also real evidence that the main deposit of petroleum occurs directly below.

1. *Oil Seepages.*—Seepages may exist in one of two forms: (*a*) where the outcrop of an oil-sand reaches the surface; or (*b*) where there is a crevice or a fault through which the oil has risen to the surface from some depth. Seepages are commonly found in the lowlands, in swamps, or along small streams; sometimes they occur merely as a faint scum on the water; but one case has been seen by the author in Mexico where oil and asphalt are running down the side of a small basaltic hill from 100 ft. or more above its base. Generally the upper part of an outcrop of an oil-sand will have lost its signs of oil, owing to weathering; but sometimes oil will still be found in the same stratum at water level.

It is very important for the novice to distinguish between scums of oil and those of other substances on water. For instance, "iron scum" has, times without number, been mistaken for petroleum, and would-be investors have paid thousands of dollars for expert examination of territory on such slight evidence, where the expert, on his arrival at the locality, was able to say at once that the scum was not petroleum, and in some cases that the formation of the country was entirely unsuitable for its occurrence. As a rule, where a film of petroleum is present, it can be distinguished from that of iron by its odor. An old hand at the business will always be able to distinguish the two substances; and often a novice can distinguish them by remembering that even a drop of oil on a water surface will expand as a thin film, giving an iridescence enlarging from a center. In the case of "iron scum," a small stick thrust into it will break it up into separate patches, while an oil scum is so thin and cohesive as to retain its iridescent and unbroken appearance.

As a rule, oil seepages exist as very faint scums on the surface of rivers or lakes, this having been true in certain of the Pennsylvania and West Virginia oil fields in the early days of their discovery. In other cases, however, as in Mexico, the tarry oil emerges from the earth in very large quantities; and ancient reports state that in certain biblically mentioned localities it formerly gushed out in great streams. In the past, rivers of oil are reported to have emerged from beneath the Caspian Sea;

and there is no doubt that natural explosions of burning petroleum have taken place, throwing masses of clay and stones into the air, uplifting the bottom of the sea locally and giving rise to small islands in the vicinity of Baku.[1]

In the larger seepages one can see the green or black oil in drops or patches, which are frequently associated with a tarry or asphaltic substance; and gas may sometimes be observed bubbling through the water at the same point. While oil seepages are generally very small, an instance has been mentioned by Craig[2] where as much as 20 bbl. of oil per day flows naturally to waste into a stream from a certain outcrop. A few cases are known where oil has come up through the ocean and appeared on the surface of the water, such an instance being reported from near Baku in the Caspian Sea, and similar occurrences exist on the coast of South America and of Trinidad.

A question will naturally arise in considering such productive oil fields as are found in Pennsylvania, Ohio, West Virginia, Oklahoma and Illinois, namely, why oil seepages have been seldom known. The reason is that the beds are so slightly tilted as to remain unbroken and there has been no fissure or other channel by which the oil could reach the surface, except perhaps in the minutest quantities. Moreover, where these formations actually reach the surface in a neighboring locality, the oil has already leaked away, owing to the fact that productive strata in those States are of Carboniferous and earlier age, and there has been plenty of time for the oil to disappear. In California and Mexico, however, where seepages are so abundant, the formations are of more recent age, namely, Tertiary and Cretaceous, so that, even though the sands are tilted and eroded at the surface, the oil has not yet entirely disappeared.

2. *Natural Gas Springs.*—In some places in Ohio and West Virginia, bubbles of gas rise in minute quantities through the water to the surface of streams. At other places, as, for instance, in the peninsula of Baku in European Russia, gas has been actually burning for thousands of years, so that it has given rise to a peculiar sect, the "Fire Worshipers." Great gas springs exist in Hungary as well as in the United States and elsewhere. Gas springs, while not being an actual proof of the existence of oil in a locality, show us that conditions are favorable, for where

[1] A. de Lapparent, "Traité de Géologie," **1883**, p. 490.

[2] E. H. Cunningham-Craig, "Oil Finding," **1912**, p. 90.

we find natural gas, it is logical to expect petroleum also within the lateral range of the existing formation.

3. *Outcrops of sands impregnated with tar or bitumen* are not common, but they exist in several parts of the world. Perhaps the best occurrences of this kind are the "tar sands" of the Athabasca and other rivers in northern Alberta in Canada, where the outcrop of the Dakota formation is impregnated with tar for scores of miles along the main rivers, leading to the supposition that oil and gas will be found in great quantity in those portions of the same sands which are under cover and have the requisite geologic structure.

4. *Bituminous Dikes.*—As to dikes of asphalt and other bitumens, the relationship is not so apparent, since these substances are frequently solidified, and some varieties of them are as hard and compact as coal. This has been so deceiving to the public that in reference to one case at least, namely, the Albert Mines in Albert County, New Brunswick, the Courts have decided that the material (albertite) shall be legally known as coal. In reality, however, it is an entirely different bitumen. In other localities, such as Mexico and California, oil is seen to ooze out of the ground, together with the asphalt, thus proving a close relationship.

5. *Bituminous Lakes.*—Asphalt and related bitumens occur elsewhere at the surface in the form of lakes. In Mexico are a great number of seepages, some of small size, but many of them covering thousands of square feet, in which the asphalt has been seen emerging from the ground and taking the form of small lakes. The best known example of a lake of asphalt is the Pitch Lake of Trinidad, hundreds of acres in area, frequently described in literature.

Asphaltic deposits are direct evidence that oil does exist or has existed in the vicinity, for these substances appear to be the desiccated or oxygenated residues of heavy oils which have oozed out of the surface in past ages. In many cases it is possible for a geologist to locate the field from which the asphalt has escaped. Consequently, it is important not to neglect the surface evidences; but in studying them, one must remember that certain structural relations hold true, and consequently that oil pools will very seldom be found directly underneath the points of emergence of the substances.

Supposed Indications.—It is true that in some localities in Louisiana and Rumania, petroleum is associated with salt in such a manner that there would appear to be a direct relationship, as certain German, Hungarian and Rumanian geologists and chemists have assumed. Perhaps the idea that oil and salt are necessarily associated is derived in part from the fact that oil was originally discovered in the United States during the search for brine, which was at one time obtained from wells in Pennsylvania and West Virginia. Many persons have assumed that salt is an indication of petroleum or natural gas.

On the other hand, it is a fact that extensive masses of salt often exist entirely unassociated with oil, this being the case in Ohio and Ontario. Consequently, recent theories respecting the origin of petroleum have mainly ignored any relationship with salt as a factor in the process, assuming first that brine, where found in an oil field during the drilling for oil, is a normal constituent of deeply buried formations of marine origin. While the connection of oil with dome-shaped masses of salt, as in Hungary and Louisiana, may be due to the fact that oil, when existent in a suitable formation, becomes concentrated against the salt mass, as a suitable factor of interruption, nevertheless the frequent occurrence of oil with salt seems to indicate some possible relationship in their origin.

It has also been assumed by some investigators that mud volcanoes are necessarily associated with oil, but this also is doubtful, since mud volcanoes are known to exist in parts of the world where oil has never yet been discovered.

Boverton Redwood states[1] that "in Russia and India the relation between petroleum and mud volcanoes is very noticeable;" and he goes on to say that mud volcanoes are generally considered as a favorable indication for the presence of petroleum, as has also been asserted by Mendeléeff, Dalton and others. Mud volcanoes are known to be found in the vicinity of the oil fields of the Caucasus mountains at Taman-Kertch, in the Apscheron, Crimean and Taman peninsulas, in Venezuela, in northern Columbia, at Minbu and the Island of Ramai in Burma, and also to some extent in Transylvania and Galicia. At Baku in the Apscheron peninsula, they have been known for centuries, and have been associated with large quantities of natural gas and petroleum. The height of the mud volcanoes near Baku

[1] "A Treatise on Petroleum," 3d ed., **1913, 1,** 122.

is reported sometimes as much as 1,300 ft., while those of Transylvania, on the other hand, are seldom over 30 ft. in height.

While natural mud volcanoes are not known to exist in the United States, there are, however, certain very voluminous natural gas wells in the Caddo field of Louisiana and in certain parts of Oklahoma, where the formations are comparatively soft and of a clayey texture, which have broken loose, bursting into the air, and continued to run wild, throwing water and mud into the air for years. These might almost be classified as artificial mud volcanoes, and it is easy to imagine that they may be of similar internal structure to the natural mud volcanoes. They are, however, evidences of gas and not of oil. It is probable that the occurrence of mud volcanoes is not necessarily associated either with natural gas or with petroleum in quantity, and that they may occur even where small amounts of any kind of gas are imprisoned in or below the muddy strata, and the escape of such gas will throw the mud into the air.

Summarizing the foregoing statements regarding the relationship of surface indications to petroleum, it must be acknowledged that surface indications of any kind are not essential, since many fields, such as those in Ohio, Indiana, Illinois and certain parts of Oklahoma, show an absolute lack of surface indications, oil never having been discovered until it was tapped accidentally by the drill or located on favorable geologic structures. We can say, however, that where oil seepages exist, they indicate oil below the surface in greater or less quantity. Similarly, since it is known that asphaltic deposits have come from oil, it may be said that oil has once existed in localities of such deposits, and it is a question for the geologist to decide whether or not the conditions are such that oil may still be expected there. In many localities where the asphaltic deposits are very old geologically, the oil seems to have completely disappeared. Where natural gas is present without oil, there is no direct evidence of the latter; but since gas and oil are believed to be derived from a common source, it is important to look for the geologic evidences of oil somewhere in the region.

It is, of course, necessary for the expert to take account of all such occurrences as may prove the general region favorable; but he must be on his guard not to give undue weight to the chances in the particular locality where a "surface evidence" is seen. Many persons have supposed that occurrences of hy-

drogen sulphide are favorable to oil; but there seems to be no certainty of this. We should also mention the great deposits of bituminous shale which exist in some parts of the world, and which, although not commercially workable in many cases, prove that oil exists potentially in greater or less quantity.

One of the greatest mistakes made throughout the early development of petroleum in the United States was the supposition on the part of a majority of prospectors that the oil fields ran universally in a given direction, and, with that idea in view, the men who were searching for oil, drilled thousands of wells on 45° lines and 30° lines. Underlying the idea was the fact that the general trend of the Appalachian oil fields as a whole and certain other fields, is from northeast to southwest. Consequently, drilling in that general direction is somewhat more likely to strike oil than along southeast-northwest lines; but, on the other hand, the southwesterly trend of the fields is only true in a very broad sense, and an individual pool is just as likely to disappear toward the southwest as to be continued in that direction. The only class of lines which are of real value in prolonging oil pools are "structure contour lines," drawn by the geologist on his maps, and which, when followed outward from an initial well, will furnish some clue to the probable direction of the extension of the pool.

Geological Age of Formations Producing Petroleum.—Petroleum has been found in rocks of practically all geologic ages from the Cambrian up to the most recent; consequently, one cannot determine, simply by a knowledge of the age of the formation, whether or not oil will be found. It is, however, very valuable, in a given field, to know that the stratum is of the same age as some producing stratum in an adjoining field, since this leads one to infer similar favorable conditions.

Table III, compiled from various sources, presents an outline of the formation in which petroleum is known in the United States and Canada.

Character of Formations Containing Petroleum.—The greater part of the petroleum of the world is found in sandstones, sands and limestones, but certain cases are known where it exists in shales, and it has even been reported in small quantities in igneous rocks. Since strata yielding petroleum are geologically identical with those yielding natural gas, it is necessary to consider the two substances together to a certain extent.

TABLE III.—GEOLOGIC FORMATIONS IN WHICH PETROLEUM IS FOUND IN THE UNITED STATES AND CANADA

Era	System	Geological group	Locality
Cenozoic	Quaternary	Recent	Texas and Louisiana.
	Tertiary	Pliocene series	California and Wyoming.
		Miocene series	California and Wyoming.
		Eocene series	California.
Mesozoic	Cretaceous	Upper Cretaceous	Alberta, California, Wyoming, Texas Colorado and Louisiana.
		Lower Cretaceous	Louisiana and Wyoming.
	Jurassic	Sundance formation	Northeastern Wyoming.
	Triassic	Chugwater formation	Wyoming.
Paleozoic	Carboniferous	Permian series	Texas and Oklahoma.
		Pennsylvanian series	Oklahoma, Illinois, Pennsylvania, West Virginia, Ohio, Kentucky, Alabama, Kansas, Indiana, Wyoming, California, Texas and Utah.
		Mississippian series	Illinois, Indiana, West Virginia and Oklahoma.
		Pocono series	Pennsylvania, West Virginia, Ohio and Kentucky.
	Devonian	Chemung & Catskill	Pennsylvania, West Virginia and Ohio.
		Hamilton	Ontario, Canada.
		Corniferous	Ohio, New York, Indiana and Ontario.
		Oriskany	New York, Indiana and Ontario.
	Silurian	Guelph	New York and Ontario.
		Niagara	New York, Ohio, Indiana, Illinois and Ontario.
		Clinton	Ohio and Ontario.
		Medina	New York and Ontario.
	Ordovician	Trenton	Ohio, Indiana, New York, Kentucky and Ontario.
	Cambrian	Quebec group	Newfoundland, Quebec and Alberta.

We may classify the formations which contain petroleum as "reservoir rocks," and this term is particularly appropriate since it seems probable that they are in truth merely reservoirs, the contents of which have been generated in underlying strata and have been collected in these formations, since the latter are particularly porous.

The question of the derivation of the oil is, of course, bound up with its origin, but it seems probable that there are certain limestones to which the oil may be indigenous, as, perhaps, the Trenton limestone of Ohio, the Tamasopo limestone of Mexico, and certain other great limestones; but, as stated elsewhere, no particular theory as to the origin of petroleum is advocated in this work.

The porosity, or capability of sandstones and sands to hold oil, is due to the shape and arrangement of the grains. Oil-well drillers refer to certain sands as "oil-sands," "gas-sands," "water-sands," or sands from which nothing is expected; and it seems that with their long experience in the business, they often have a faculty of noticing certain characteristics regarding shape of grain, etc., which determine the factor of porosity.

In limestones, the question of porosity is somewhat more complex. There is no doubt that in certain limestones petroleum occurs in greater or less quantity, in real cavities which have been caused by solution of the rock. In other limestones, however, the porosity is due to the fact that the rock has been changed locally from limestone to dolomite, giving a phase of interlocking crystals, in which the oil is held. The change is due to the conversion of the calcium carbonate which composes the limestone into the calcium and magnesium carbonate which mineralogists know as dolomite and which occupies less space than the limestone. The Trenton limestone of Ohio and Indiana is thus altered along the crest of the Cincinnati anticline.

In the case of sandstone, the occurrence of oil is due not only to structure, but is affected also by the continuity of the stratum. Well drillers recognize the internal variations when they speak of a sand being "open" or "close," "soft" or "hard," and "good" or "poor" in character. An experienced driller may determine the petroliferous possibilities of a sand by visual examination, but he is unable to determine definitely whether it would be productive without knowing the geological structure of the locality in question.

The question of the amount of oil which a certain formation can contain in view of its porosity is a rather complicated subject. It is discussed by Redwood[1] in some detail, and will not be gone into here. Interwoven with this same subject is the question of the distances which one well will draw oil from another, and many other questions encountered in the drilling of an oil field.

Stratigraphic Relations of Petroleum.—The conditions under which petroleum exists in the earth are both stratigraphic and structural. The principal requisite for a productive oil field consists of a porous reservoir rock overlain by an impervious cover. As stated elsewhere, the reservoir rock is commonly sandstone, sand or limestone, and the cover is most frequently shale; but there are many different exceptions to and modifications of this rule. It is a fact, however, in a field of large volume, that there must be some sort of a continuous cover to prevent the oil from leaking away to the surface and disappearing, and this is what must have happened in some great fields from which the oil has long since vanished.

Ordinarily the bed of impervious rock overlying a "sand" which holds oil or gas, is known as the "cap-rock." It is frequently very hard, though not always, and generally consists of limestone or shale. One of the most widespread formations overlying gas- and oil-sands is the Utica shale above the Trenton limestone in the Ohio-Indiana fields. The Clinton sand of central Ohio is overlaid in a similar way by the Clinton shale. The numerous oil- and gas-sands of Pennsylvania and West Virginia are all overlaid by impervious shales. In the Louisiana fields a hard stratum of limestone sometimes acts as a cap-rock overlying a more pervious portion of the same formation. In fact, "cap-rocks" may consist of almost any relatively impervious material, even dense sandstone answering in some fields.

Structural Relations of Petroleum.—One of the most important matters to understand in connection with the geologic aspects of petroleum is the relationship in which oil, gas and water are found in view of their different specific gravities. Where these substances exist in any sand, it is very probable that they were originally intimately mixed, but that the tilting or folding of the strata from geologic causes have separated out the different

[1] Boverton Redwood, "A Treatise on Petroleum," 3d ed., **1913, 1,** p. 113.

substances, segregating the water into the lower parts of the porous strata, the oil higher up, and the gas into the very highest portion of the strata which it can reach. This relation is a fundamental consideration in the discussion of oil geology, since it means that where the sands are absolutely dry the oil will be found low in the synclines or basins; whereas, where the sands are wet, the oil in many cases will have been forced up by the water to the crest of a dome or anticline. In practically all instances, however, the oil lies lower in the formation than does the gas, and it generally rests upon water, when the latter is present.

Movements of Oil in the Strata.—A subject on which the majority of oil geologists are agreed is that petroleum is not limited to the formation in which it originated, but has migrated and is sometimes still migrating. This necessitates an understanding of the movements of oil through rocks, and an excellent description of these has been given by Campbell.[1]

So far as known there are three forces which are mainly responsible for the movements of oil through the rocks and its segregation: (1) gravitation, (2) capillary attraction, and (3) differences in specific gravities. It is probable that the gravitative factor is very simple and practically negligible, on account of the friction which would be encountered by the oil in moving through the rock. Capillary attraction, however, is much more powerful than is gravitation and is supposed to be an effective agent in the movements of oil.[2] As has been shown by Day,[3] petroleum will diffuse readily in all directions through dry clay and shale, and in this diffusion the oil may be separated into fractions of different specific gravities. This process probably takes place frequently in dry rocks; but in those saturated with water the capillary factor is likely to be overshadowed by the presence of water. Moreover, capillary attraction takes place only in rocks having extremely small pores, such as clays or shales. These rocks when moist are impervious to oil, which may be the main reason why a cap-rock of clay or shale is best

[1] M. R. Campbell, "Petroleum and Natural Gas Resources of Canada," *Canada Department of Mines, Mines Branch*, **1** (1914), pp. 76–89.

[2] C. W. Washburne, "The Capillary Concentration of Gas and Oil," *Am. Inst. Min. Eng., Bull.* No. **93** (1914), 2365–2378.

[3] David T. Day, *Proc. Am. Phil. Soc.*, **36**, No. 154, 112–155; also *Trans. Am. Inst. Min. Eng.*, **41**, 219–224.

fitted to hold the oil in the reservoir below it. It is a great question as to whether capillary attraction, notwithstanding its great force, has been sufficiently widespread or continuous to be the most important factor in oil movements and accumulation. In connection with capillarity, it has been shown by Day[1] that oil will diffuse readily through dry fullers' earth, but that moistened earth is impervious; hence the cap-rock overlying the oil reservoir may consist either of fine-grained impervious rock or of fine material saturated with water.

The principal factor in the movement and accumulation of oil appears to be specific gravity, or, more accurately speaking, the *difference* in the specific gravities of water, oil and gas. As explained by Campbell,[2] water has presumably been such a powerful factor in the movement of oil that it has always pushed oil ahead of it when moving up the dip of a porous stratum; consequently, where the rocks are saturated, the oil has finally been accumulated on the highest portion of an anticline or dome. Moreover, it is probably true that in cases where the saturating water has been removed subsequent to the time of structural change, the associated oil will still remain in a high portion of the stratum, since it does not move readily by the force of gravitation alone. In localities, however, where the reservoir rocks were dry at the time of structural change and are still dry, the oil may be found in the synclines; this is frequently true in West Virginia and in some parts of Pennsylvania.

Another view, originally proposed by Munn, is that the movements of oil are bound up with the hydrostatic conditions in the stratum, as affected by the overlying surface topography, and consequently that the present accumulation of oil bears a definite relation to the present water circulation; but this theory has not met with wide acceptance. In any case, both the advocates and opponents of the anticlinal theory seem to have generally assumed that oil rocks are saturated with water; but such is not universally true, and hence the structural relations of oil are quite different where water is or has been present from what they are where it has been absent. Therefore, one of the first requisites in examining an oil field is for the expert to determine whether the rocks are wet or dry.

[1] David T. Day, "The Conditions of Accumulation of Petroleum in the Earth," *Trans. Am. Inst. Min. Eng.*, **41** (1911), 212–224.

[2] *Op. cit.*, p. 79.

It should not be assumed that all beds of sandstone or all parts of any particular sandstone stratum are capable of holding oil, for there are many sandstones and many portions of every sandstone which are too hard to contain oil, and in many cases the grains are so closely cemented as to make the rocks practically impervious.

The movements and methods of accumulation of oil into definite pools are presumed by Campbell to be somewhat as follows, and these movements seem to be generally accepted by oil geologists:

"Urged on by the difference in specific gravity, the oil will rise through the interstitial pores in the rock. If the rock consists of a great mass of sandstone, the oil will be forced to the top of the bed unless it has been arrested in transit by a barrier of impervious sand or a clay-sealed fault. After reaching the top of a particular 'sand,' be it thick or thin, the oil, if still forced by the water behind, will seek to escape into the overlying bed; but if this bed be composed of impervious clay or shale, the oil will be confined to the one stratum. When so confined, its movement will depend almost entirely upon the attitude of the bed or, in other words, upon the geologic structure. If the bed lies nearly horizontal, there is manifestly no place to which the oil can migrate and then it collects in the uppermost layers of the sand. Beds of rock, however, seldom retain their horizontality for any great distance. If they rise, the oil will tend to move in this direction, but whether this tendency develops into actual motion will depend largely upon the degree of inclination of the bed. If the dip is slight the pressure resulting from the difference in specific gravities of the water and oil may not be sufficient to drive the oil through the open sand; but in case the bed is sharply tilted, the oil will move freely, provided that the sand maintains its open, porous character. This fact explains one of the conditions controlling accumulation of oil—a condition that is probably most marked in the case of the Ohio-Indiana pools in the Trenton limestone."

Types of Geologic Structure with Which Oil Pools are Associated.—In considering the geological structure of oil fields, much has been written on the "anticlinal theory," which still has its advocates and opponents. This theory has been of great value in locating oil fields, but petroleum is also subject in its occurrence to other factors, which account for the apparent failure of the theory in some localities. Moreover, petroleum occurs in other types of geological structure than anticlines, and a knowledge of all these types is necessary to a geological engineer in making predictions of value.

The anticlinal theory was first suggested by T. Sterry Hunt,[1] and has been investigated and advocated by E. Benjamin Andrews,[2] Alexander Winchell,[3] J. J. Stevenson,[4] F. W. Minshall,[5] J. S. Newberry,[6] Hans Höfer,[7] and others. The theory was not definitely formulated, however, until 1885, when I. C. White[8] worked out its details and applied the theory in practice by locating oil and gas fields in West Virginia and Pennsylvania by means of it. White's theory was at first applied strictly to supposedly saturated rocks. In dry rocks somewhat different conditions exist, and in such instances the theory is modified. Edward Orton[9] also deserves great credit for parallel lines of research which deciphered the geologic structure of certain terraces. The various stages in the anticlinal theory have been ably summarized by Campbell.[10]

In order to consider the various types of geological structures with which petroleum is now known to be associated, the author of this Chapter has had occasion to classify them. The original classification was published in *Economic Geology*,[11] referring to accumulations of gas as well as of oil.

In any accumulation based on geologic structure, the structure of the productive stratum itself must be considered independently of the configuration of the surface or structure of any surface formation. The object of the classification is to describe the various types of accumulations of petroleum by grouping them

[1] "Notes on the History of Petroleum or Rock Oil," *Can. Nat.*, **6**, 241–255 (August, **1861**); *Canada Geol. Survey, 17th Rept. of Progress*, **1863–66**, 233.

[2] "Rock Oil, its Geologic Relations and Distribution," *Am. J. Sci.*, (2), **32**, 85–93.

[3] "On the Oil Formation in Michigan and Elsewhere," *Am. J. Sci.*, (2), **39** (1865), 352.

[4] *Second Geol. Survey of Pennsylvania*, (H), **1875**, pp. 394–5.

[5] In letters to the *State Journal* of Parkersburg, West Virginia, in **1881**.

[6] *Geol. Survey of Ohio*, 1 (1873), 160.

[7] "Das Erdöl und seine Verwandten," 3d ed., p. 166; "Geologie des Erdöls," p. 18.

[8] *Science*, **6**, June 26, 1885; *Bull. Geol. Soc. Am.*, **3** (1892), 187–216; and *W. Va. Geol. Survey*, **1–A**, 1904, pp. 48–64.

[9] *Geol. Survey of Ohio*, 1886, **6**, pp. 21 and 94.

[10] "Historical Review of Theories Advanced by American Geologists to Account for the Origin and Accumulation of Oil," *Econ. Geol.*, **6**, No. 4, 363–386.

[11] F. G. Clapp, *Econ. Geol.*, **4** (1909), 565–570.

into classes, each division of which follows a special rule of structure, and all of which have certain aspects in common.

The classification as elaborated to date, is as follows:

CLASSIFICATION OF PETROLEUM ACCUMULATIONS BASED ON GEOLOGIC STRUCTURE

CLASS I.—Where anticlinal and synclinal structure exists.

(a) Strong anticlines standing alone.

(b) Well-defined anticlines alternating with synclines.

(c) Structural terraces.

(d) Local warpings on monoclinal dip.

(e) Accumulations on monoclines, due to thinning out or change in texture of the sand.

(f) Broad geanticlinal folds.

(g) Overturned folds.

CLASS II.—Quaquaversal structures.

(a) Anticlinal bulges, or "cross anticlines."

(b) Saline domes.

(c) Volcanic necks.

(d) Perforated domes.

CLASS III.—Joint cracks.

(a) Joint cracks in sedimentary rocks.

(b) Joint cracks in crystalline rocks.

CLASS IV.—Sealed faults.

CLASS V.—Oil sealed in by asphaltic deposits.

CLASS VI.—Contact of sedimentaries with crystalline rocks.

Class I. Where Anticlinal and Synclinal Structure Exists.—This is the type of petroleum accumulation with which we are most familiar. It predominates in a large majority of the known oil fields of the world, including the Appalachian, Illinois, Indiana, Mid-Continent, Wyoming, Colorado, northern Louisiana, northern Texas, and some of the California fields in this country, and Russian, Austrian, Burma, and Borneo fields in the eastern hemisphere. Class I is divided into seven subclasses, in order to distinguish between various structural relations in which oil is found in connection with anticlines and synclines.

Subclass (a). Where Strong Anticlines Exist Standing Alone.—In this division should be included fields that bear a direct relation to *very pronounced* uplifts, easily recognizable, and which constitute a marked geologic feature of the region. The only prominent example in the eastern fields of the United States is

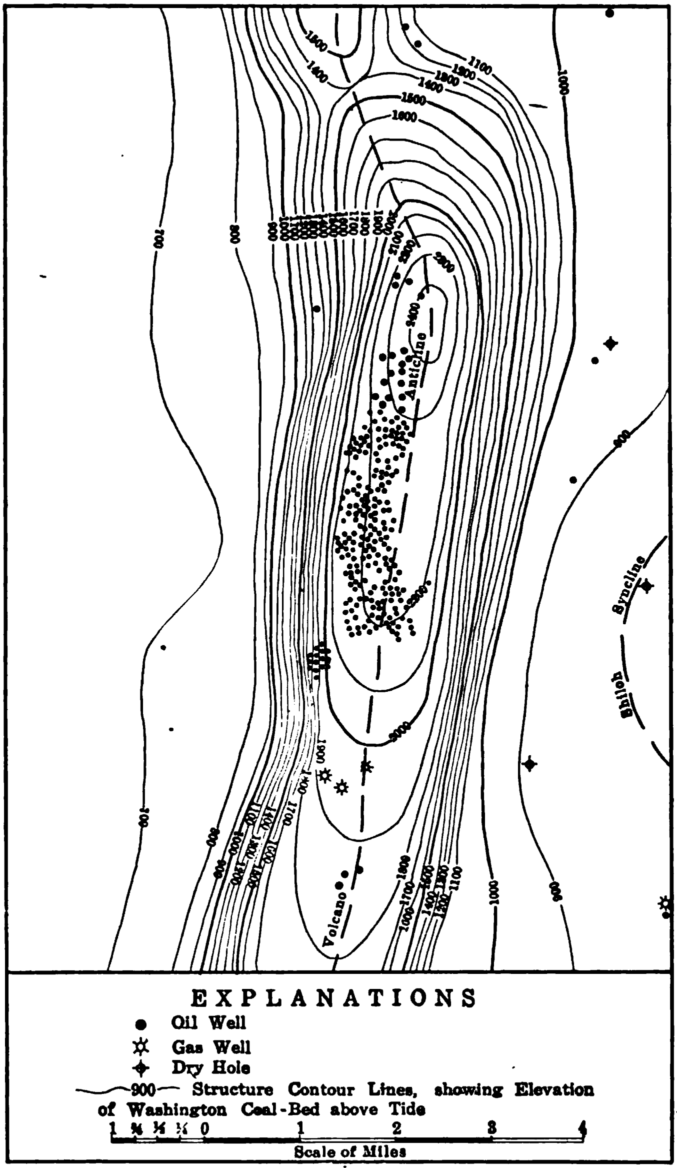


FIG. 2.—Sketch map of a portion of the Volcano anticline in West Virginia, to illustrate the occurrence of petroleum according to Subclass I (*a*). The oil is found on the flat crest of the highest portions of the anticline. (After G. P. Grimsley, *Rept. W. Va. Geol. Survey*, **1910**.)

the Volcano anticline in Pleasants, Wood, Ritchie and Wirt counties in West Virginia. This anticline is 25 miles in length, and ranges in direction from north 20° west to north 20° east, from an eighth of a mile to over a mile broad on its flat crest, and has side-dips in places as high as 20 to 60°. A structural map of it in part is given in Fig. 2. The anticline differs somewhat in direction from the main Appalachian folds, and was probably produced by a different set of forces. It is one of the earliest recognized anticlines in the country, and probably has had as many wells drilled on it as any other. It has been described by White,[1] Andrews[2] and Evans. Some of the California fields which have sharp anticlines probably belong to this class, and perhaps the Baku fields of Russia should be placed here.

Subclass (b). Where Well-defined Alternating Anticlines and Synclines Exist.—With minor exceptions this subclass includes all pools in the Appalachian field in Pennsylvania, West Virginia, eastern Kentucky, the fields of southern Indiana and Illinois, certain Oklahoma fields, part of the Caddo field of Louisiana, certain fields of northern Texas, Colorado and Wyoming.

The Caddo field has geologically nothing in common with the Beaumont and Jennings fields and others of the Coastal Plain in Louisiana and Texas, but it has certain similarities in structure with the fields of Pennsylvania, West Virginia, and Illinois. In northern Louisiana the oil-accumulating structure is afforded by the Sabine uplift, and the final distribution of oil and gas there appears to be due to minor anticlines and synclines, accompanied by differences in porosity of the Upper Cretaceous formations.

Several of the California oil fields also belong in this subclass, viz.: the Coalinga field and the Los Angeles field, according to descriptions by Eldridge[3] and by Arnold and Anderson.[4] In 1895, Noetling established the fact that the oil fields of the Irrawaddy, in Burma, correspond with the structural theory; and they presumably belong in part in this subclass. The oil in those fields is directly related in its distribution to anticlines and domes in the Miocene sandstone.

[1] I. C. White, *Bull. Geol. Soc. Am.*, **10** (1899), 29.

[2] E. B. Andrews, *Am. J. Sci.*, (2), **32**, 85–93.

[3] Geo. H. Eldridge, *Bull.* **213**, *U. S. Geol. Survey*, pp. 306–321 (1902).

[4] Ralph Arnold and Robert Anderson, *Bull.* **357**, *U. S. Geol. Survey*, pp. 70–71 (1908).

The rocks in the fields comprised in subclass (*b*) are folded into alternating anticlines and synclines of moderate dip, which is seldom as much as 30° from the horizontal. This is the subclass to which the anticlinal theory was originally applied. As natural gas occurs in the upper part of individual sands, or "pay streaks," the oil occurs somewhere below the gas, while salt water, when present, fills the remaining space in the sand, if the latter is uniformly porous, or occurs in separate "pays," where the sand as a whole has not a high degree of porosity. The position of all these deposits is controlled primarily by force of gravity. Where oil or salt water occurs higher than gas in the sand, it is presumably due to sharp changes in the dip, or to a multiple nature of the "pay streaks."

Subclass (*b*) is illustrated in Fig. 3, where an oil field is seen occupying the side of an anticline, while a gas field occupies the crest.

Subclass (*c*). *Structural Terraces* are an exaggerated form of the flattenings of dip which are included in subclass (*d*). As a rule, where gas exists, it is found on the outside of the terrace, with oil on the inside and round the edges, though this is not an infallible rule. The change in the rate of dip forms a local interruption and seems to be the essential factor.

The effect of terrace structure was first explained and illustrated by Edward Orton in 1866.[1] In the Findlay field of northwestern Ohio, described by him, oil and gas were found in two terraces, separated by a monoclinal dip. The upper terrace yielded dry gas, the lower terrace yielded oil and water. Orton gave the name "arrested anticlines" to structural terraces, and cited the Macksburg field of southern Ohio as an example.[2] The terrace structure of the Macksburg field was first recognized and described by Newhall in the same volume.

During the past two decades, hundreds of similar terrace structures have been discovered throughout southeastern Ohio, northern Oklahoma, West Virginia, and, to some extent, in other states, and most of them are available for oil or gas development. Generally, though not always, the structure can be practically determined from the geology of the surface without the necessity of borings until one is ready to make his test. Other good examples of terrace structures and relations of oil to them were

[1] *Science*, **7**, 563.

[2] "Geology of Ohio," **6** (1888), 94.

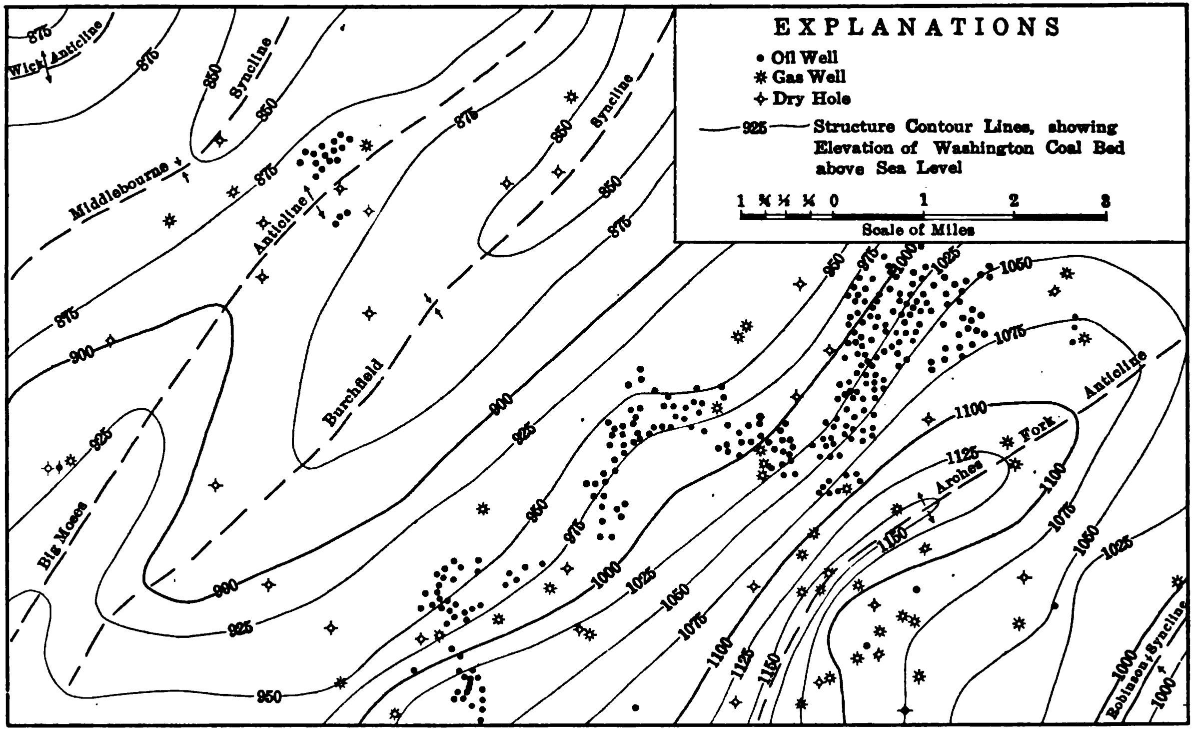


FIG. 3.—Sketch map of a typical oil and gas field in West Virginia, to illustrate Subclass I(*b*). Note that the gas field corresponds with the crest of the anticline, while the oil field is part way down its side into the adjoining syncline. (After R. V. Hennen, *Rept. W. Va. Geol. Survey*, **1911.**)

shown by Griswold and Munn in Jefferson County, Ohio,[1] and Fig. 4 is an illustration of this class of structure taken from their report.

Subclass I (d). Local Warpings on Monoclinal Dip.—This may be considered as a less prominent form of I (*c*), in that the terrace is not a well-defined one; but there are slight flattenings and inward and outward warpings with which the oil is associated,

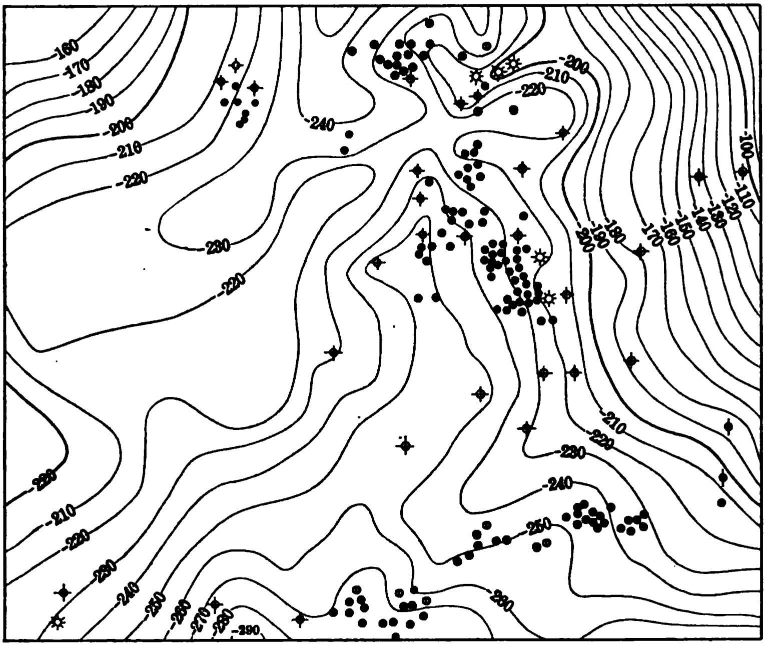


Fig. 4.—Sketch map to illustrate the occurrence of petroleum on structural terraces, according to Subclass I(*c*). (After Griswold and Munn. For explanations, see Figs. 3 and 5.)

since these furnish interruptions and thereby facilitate the segregation of the oil pools. One type of these warpings is shown in Fig. 5, which is an illustration of a small pool in Pike County, Ohio.

While subclass I (*d*) has been noticed by the author mostly in Ohio and Oklahoma, a number of examples have been reported by Gardner and others in Kentucky and Alabama. The majority of the oil and gas pools in southeastern Ohio belong in this subclass. Definite anticlines are not so common in Ohio

[1] *Bull.* **318**, *U. S. Geol. Survey*, **1907.**

as in Pennsylvania and West Virginia, since formations dip only in one general direction (toward the southeast). However, the application of the structural theory, properly understood, is almost as certain of profitable results as it is in Pennsylvania, for the reason that the dip is not uniform, but varies from flat to over 5° from the horizontal. Oil and gas can be predicted in subclass (*d*) through recognition of the principle that any change in the rate of dip is to be considered as a possible place of accumulation; and that such a place of accumulation once discovered,

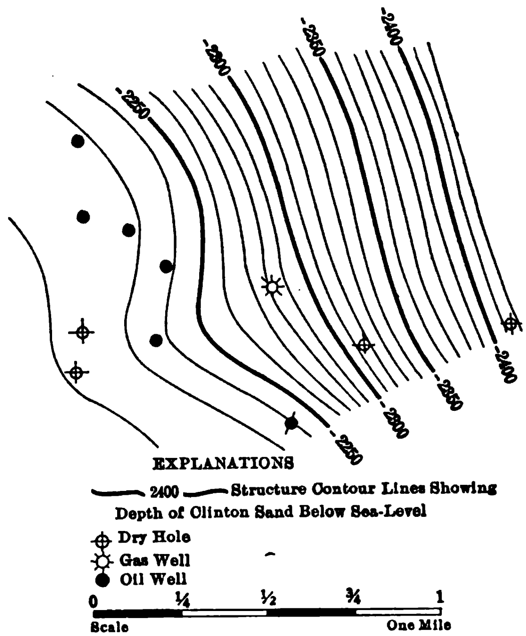


FIG. 5.—Example of Subclass I(*d*). A small oil pool coincident with a change in monoclinal dip, in Clinton sand fields of southern Ohio, examined by the author.

the pool can be easily extended (within structural and lithological limits) by following the lines of horizontality in the sand.

Subclass I (e). Accumulations on Monoclines Owing to Thinning Out or Change in Texture of the Sand.—There are doubtless a great number of instances of this type; but the best known is that of the Clinton sand of Ohio (or, in reality, a Medina sand), which rises from a great depth in the Appalachian basin, and gradually thins out as it approaches the surface in central Ohio, so that it never reaches the top of the ground, the feather edge

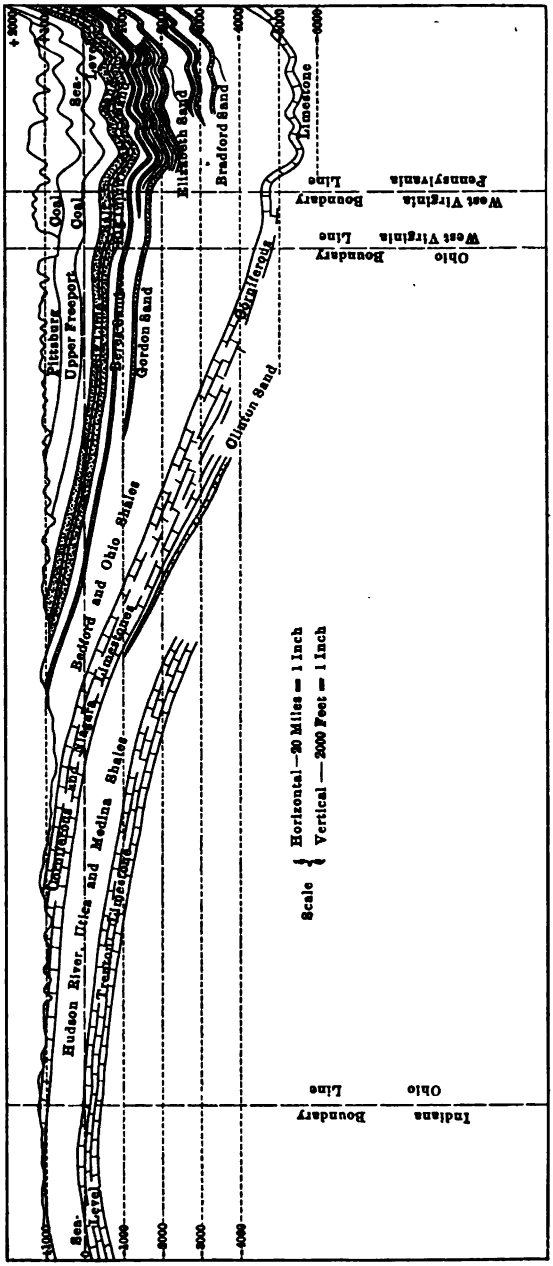


FIG. 6.—Generalized cross-section from Cincinnati anticline to the Allegheny Mountains, showing the relative position and the geological structure of the various Ohio and Pennsylvania fields, in which petroleum occurs according to Subclasses I(*b*), I(*d*), and I(*e*).

being hemmed in by shale; thus furnishing an ideal substitute for an anticline and hence this formation has become a repository of one of the greatest gas fields in the world, on the lower border of which are the Bremen, Junction City, Wooster, Straitsville and other well-known oil fields. A cross-section of the west side of the Appalachian basin, illustrating subclass I (*e*), is shown in Fig. 6. An ideal section of a pinching sand is given in Fig. 10.

Subclass (*f*). *Broad Geanticlinal Folds.*—This is an extreme type of I (*a*). By a *geanticline* is meant an anticline which is extremely long and broad, and constitutes more than a local feature, extending over thousands or tens of thousands of square miles. One of the best examples in this country is the Cincinnati anticline, in which immense reservoirs of oil and gas have been developed and exhausted, the oil and gas being contained mainly in the Trenton limestone. Owing to the broad areas under which oil is found in the Cincinnati anticline, the chances of success in drilling were originally much better than in other fields. Most of the pools in the Clinton sand in Ohio are situated along the eastern flank of the Cincinnati anticline, but these pools belong under subclass (*e*) of the classification. A cross-section of the Trenton limestone field appears in Fig. 6.

Subclass (*g*). *Overturned Folds.*—Examples of oil and gas occurring in connection with overturned folds are not common, but some such cases are conspicuous in California, as shown by Arnold and Johnson,[1] and they are reported in Galicia and elsewhere.

Class II. Domes or Quaquaversal Structures.—In the classification of oil deposits, the subdivision entitled "quaquaversal structures" is used to include all those structures in which the oil-sand dips away in all directions from a central point; thus including the saline domes of Louisiana, certain anticlinal domes in Oklahoma and West Virginia, the basalt volcanic necks of Mexico, and the perforated and non-perforated salt domes of Rumania and Hungary.

Subclass II (*a*). *The Anticlinal-bulge Type.*—This structure merges with the types described in subclasses I (*a*) and I (*b*) of the classification, since practically all anticlines consist of alternate contractions and bulges where the formations are respectively depressed or elevated.

The term "cross-anticline" has been sometimes applied to

[1] Ralph Arnold and Harry R. Johnson, *Bull.* **406,** *U. S. Geol. Survey,* **1901,** p. 97.

these domes or bulges, but not always correctly so, as, for instance, at Jacksonville, Greene County, Pennsylvania, where the deepest part of the Ninevah syncline lies directly opposite the highest part of the dome on the Washington anticline.

Anticlinal bulges are of all shapes and sizes, but those of great length would hardly be recognized as domes and are not here considered, since they belong strictly to subclasses I (*a*) and I (*b*). Anticlinal bulges exist in Washington and Greene counties, Pennsylvania,[1] in Jefferson and Harrison counties, Ohio,[2] and in Johnson and Natrona counties, Wyoming.[3] Wegemann has named this last-mentioned feature "the Powder River dome." The anticlinal-bulge type of domes has also been observed at many other places throughout Pennsylvania, West Virginia, Ohio and Oklahoma. Fig. 7 is an illustration of this type. While natural gas is more common than oil in this type of domes, oil does occur in some localities, especially where the rocks are saturated with water.

Subclass II (b). The Saline-dome Type.—This type of quaquaversal structure was described by Hayes and Kennedy in 1903[4] and more fully by Fenneman in 1906.[5] The saline domes of Louisiana were described by Harris in 1908,[6], 1909,[7] and 1910.[8] The saline-dome structure is typical of most of the fields in Louisiana and Texas within 100 miles of the Gulf of Mexico. The Caddo field and the north Texas fields, however, are not included in this type.

In southern Louisiana there are five prominent elevations known as the "Five Islands," or the "South Islands," which constitute the most conspicuous landmarks in hundreds of miles

[1] F. G. Clapp, *Folios* **144** and **146**, *U. S. Geol. Survey*, **1907**; and W. T. Griswold, *Bull.* **318**, *U. S. Geol. Survey*, **1907**.

[2] W. T. Griswold, *Bull.* **198**, *U. S. Geol. Survey*, **1902**.

[3] C. H. Wegemann, *Bull.* **471-A**, *U. S. Geol. Survey*, **1912**.

[4] C. W. Hayes and Wm. Kennedy, "Oil Fields of the Texas-Louisiana Gulf Coastal Plain," *Bull.* **212**, *U. S. Geol. Survey*.

[5] N. M. Fenneman, "Oil Fields of the Texas-Louisiana Gulf Coastal Plain," *Bull.* **282**, *U. S. Geol. Survey*, **1906**.

[6] G. D. Harris, *Bull.* No. **7**, "On Rock Salt," *Rept. of 1907, Geol. Survey of La.*, **1908**.

[7] "Geological Occurrence of Rock Salt in Louisiana and East Texas," *Econ. Geol.*, **4**, No. 1, 12–34.

[8] G. D. Harris, "Oil and Gas in Louisiana," *Bull.* **429**, *U. S. Geol. Survey*.

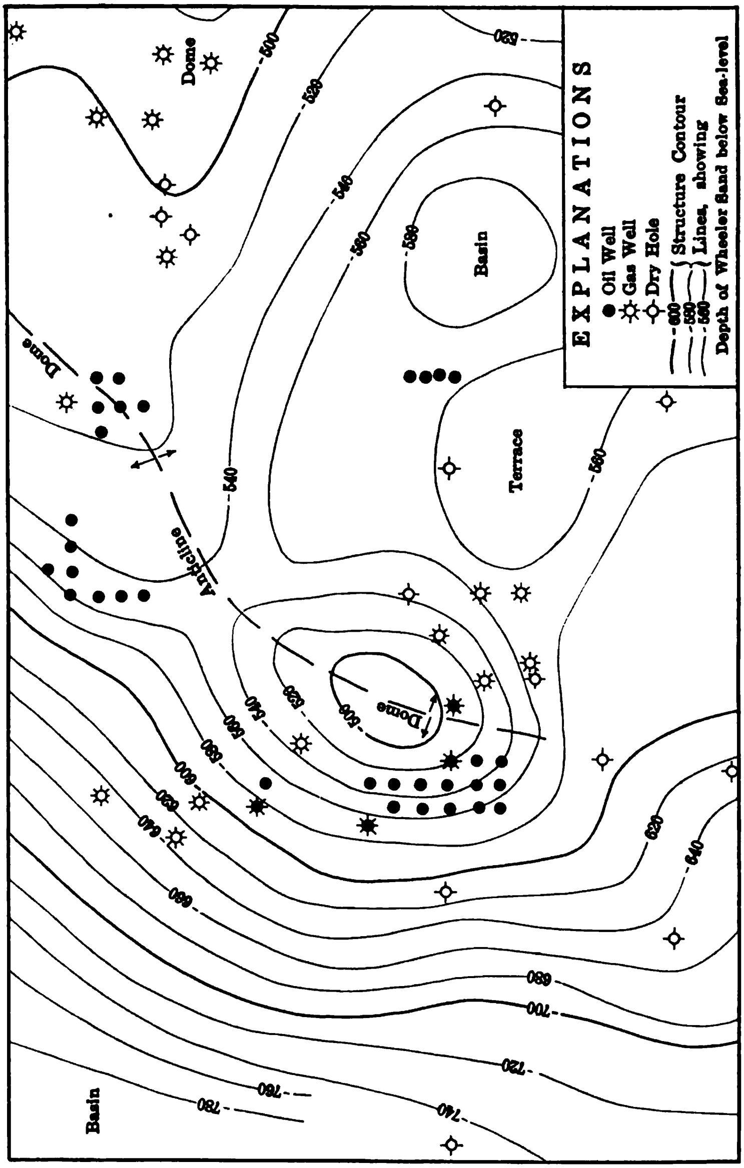


FIG. 7.—Sketch map to illustrate the occurrence of oil and gas according to the anticlinal-bulge type of dome [Subclass II(a)]. This represents a locality in Osage County, Oklahoma.

along the Coast of the Gulf of Mexico.[1] They rise from a few feet to 200 ft. above marsh level and have been frequently discussed in literature. In area they are from 200 to 1,500 acres. Salt is found in all of the Five Islands except Côte Blanche.

It should not be supposed, however, that every dome which is a saline-dome *geologically* is evinced on the surface of the plain by a *topographic* dome. While instances exist of the occurrence of mounds or small hills overlying the geological domes, the topographic dome is not a necessity to the type. The Welsh and Spindle Top pools and some others are situated where the surface is practically flat.

The configuration of the strata and the minerals underlying the saline-domes are matters of much interest and great importance, as the structure is very different from the normal southeastward dip of the Cretaceous and Tertiary beds which underlie the Coastal Plain of Louisiana and Texas. Whether or not there is any particular surface topography indicating a dome in the locality, there is a very marked geologic protuberance consisting of a sudden upward warping of the strata, as they approach the edge of the dome, so that they may stand nearly vertical round its edges. Several thousand feet of uplift in an area a mile across is not uncommon in these salines. While there are no Cretaceous beds of normal structure at the surface in Louisiana, there are several salines in which these formations reach the surface in limited areas. Beneath the Cretaceous beds and interlaminated with them in the center of the dome are extensive deposits of rock salt, sulphur, gypsum and sometimes other minerals.

In certain other fields an association of salt and sulphur is found with hydrocarbons. This holds true in Russia, Sumatra, Java, Japan, Rumania, Germany and Transylvania. Gypsum and zinc blende are occasionally found associated with these deposits, and pyrite and galenite are reported by at least one writer.

The term "dome" refers to the shape of the geologic structure, which is illustrated by Fig. 8. In the Gulf Coast oil fields, the underlying formations are domed, whether the surface is so or not. For instance, at Spindle Top the rock structure has been carefully determined on the basis of well records and has been found to have a form similar to that illustrated. The

[1] A. F. Lucas, *Trans. Am. Inst. Min. Eng.*, **29**, 464.

cross-sections of all salines which have been determined show a similar, more or less, dome-like form, although there are great differences in local conditions. As a rule, sands and shales are penetrated for several hundred feet in depth, then limestone or dolomite is encountered, below which sulphur, gypsum and rock salt are found. The character of these minerals is not supposed to have any effect on the existence of oil at the particular point; but the oil has been accumulated from the surrounding strata owing to the interruption formed by the upward doming of the sediments.

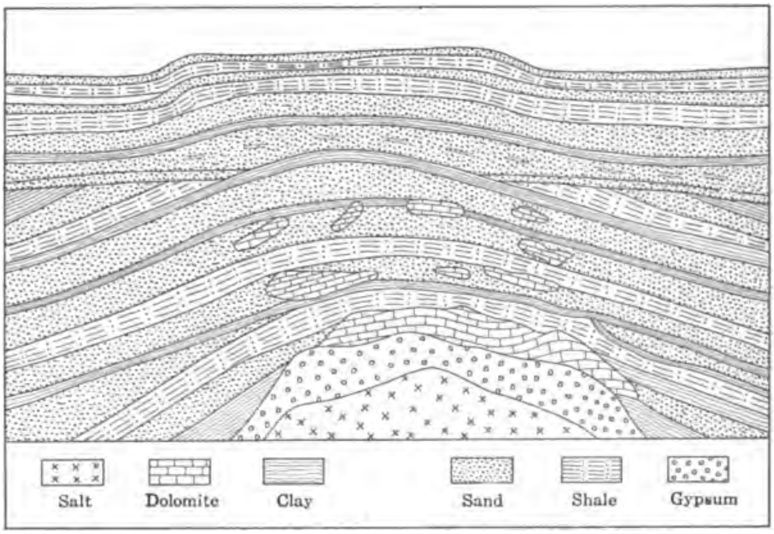


Fig. 8.—Cross-section of a typical saline-dome oil field in Texas. (After Hager.)

Salt is believed to exist in practically all domes of this subclass. The salt consists of 98 to 99 per cent. sodium chloride, except at Belle Isle, La., where it is saturated with oil. Galenite and sphalerite are also found at Belle Isle in a well drilled on the center of the dome; and at Sulphur, La., a large dome of rock sulphur has been found, in place of the salt which might be expected. Borings made for oil and sulphur at Belle Isle have revealed limestone, sulphur and escaping waters charged with hydrogen sulphide and sulphur dioxide, but the oil from these wells gives no indication of sulphur. This oil has a paraffin

base, is 45° Bé. in gravity, and is somewhat lighter in color than Pennsylvania petroleum.[1]

Although the oil seems to occur *on* the saline-domes and to accord with the anticlinal theory, it must be acknowledged that it is frequently found around the base of a dome and that there is no certainty where the oil originated. Attempts to discover its source by deep drilling have generally been abandoned, owing to the great depth of well necessary. Since the question of the origin and mode of accumulation of the oil in the domes is intimately concerned with the origin of the domes themselves, even the geologists who are most familiar with these structures seem to have abandoned any systematic attempt to explain them. Some persons who are familiar with the Louisiana structures believe that the saline-domes are simply the results of crystallization of the salt on a large scale along lines of weakness in the strata, presumed to be the crossing points of faults. Others believe that the salt and other minerals have been deposited by circulating currents of hot water. Still others suppose that the domes overlie large masses of igneous rock similar to the basalt domes of Mexico, but which have not reached the surface. An ingenious European theory is that the domes of Germany, Transylvania and Rumania have been caused by the lateral flowing of beds of salt into the domes owing to pressure in the overlying and underlying strata. So many theories, all with their advocates and all accompanied by equally good arguments, go a long way to support the view that all material theories must in time give way to something better than material.

Subclass II (c). Volcanic Neck Type.—The Coastal Plain of Mexico contains oil fields connected with several types of geologic structure, of which one at least is quaquaversal. This type consists of necks of basalt and similar rocks which rise through the Cretaceous and Tertiary sediments in the Coastal Plain, to elevations of several hundred feet. While little drilling has as yet been done in the vicinity of the necks, and the geologic structure is therefore somewhat speculative, the general cross-section is presumed to be somewhat as in Fig. 9, although recent investigations have indicated that the walls of the basalt are much steeper than shown and even re-entrant. In close proximity the formations have been domed upward, forming pockets or places of change in dip at the base of the upheavals and surrounding

[1] *Bull.* No. 7, *Geol. Survey of La.*, 1908.

them, where large deposits of oil have accumulated. In the Tamasopo limestone and San Felipe beds, these oil deposits were presumably concentrated from surrounding portions of the same strata, owing to the upheavals mentioned, possibly with the assistance of heat. The presence of the oil accumulations surrounding the necks are sometimes, although not always, evinced by large seepages of oil in the immediate vicinity.

The superficial deposits of Mexico are so deep that, whether or not the limestone beds actually reach the surface of the Coastal Plain is sometimes a matter of conjecture; but at any rate the underlying beds are domed upward by the intrusions, and it is a fact that pockets of oil generally exist there. It would appear

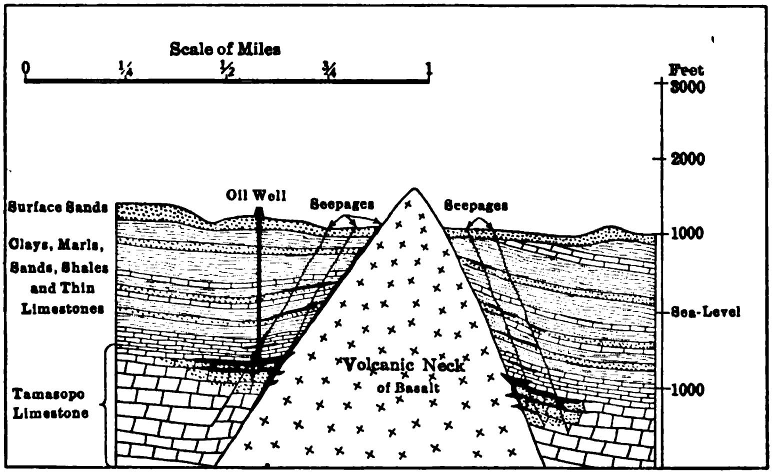


FIG. 9.—Hypothetical cross-section of a volcanic neck in the Coastal Plain of Mexico, showing the occurrence of petroleum according to Subclass II(*c*).

that large deposits of oil might be expected in the vicinity of such intrusive masses in all cases where porous sands exist overlaid by a suitable cover to prevent the escape of oil. Where the impervious covering or cap-rock is unusually massive or thick, without fractures, seepages may not exist, although they do exist in the vicinity of most of the necks, generally not far from their base. Seepages also exist along the sides of dikes which radiate from the volcanic necks; and one case was seen where asphaltic oil was flowing down the sides of a cone from a breccia included in the basalt 50 to 60 ft. above the surrounding

plain. It is supposed that this oil entered the basalt through fissures, which extend into the neck from the oil sand, and that the existence and consequent escape of the oil through the basalt was caused by the great pressure under which it exists in the sand.

The volcanic necks of olivine-basalt are scattered at wide intervals throughout the Gulf Coastal Plain of Mexico. The greatest center of volcanic activity in the Mexican Coastal Plain was the Otontepec and Tantima range of mountains, several thousand feet in height, in the State of Vera Cruz. The volcanic activity seems to have become less at increasing distances from these mountains and had practically disappeared before reaching the Rio Grande River. The majority of the volcanic necks are only a few hundred feet in height, and some of them less than 100 ft., so that many such necks presumably exist which never reached the surface.

While the largest seepages in Mexico are within a few miles of the Otontepec Mountains, seepages are also found in Amatlan, Tancoco, Tepezintla, Chapapote, Juan Casiano, Cerro Azul, and many other localities. Many of these seepages are associated with volcanic rocks. The geologic relations of the necks make it certain that they are of more recent origin than the Coastal Plain sediments, although very often no disturbance of the strata can be discovered surrounding them. In the vicinity of the Otontepec Mountains, however, there are great uplifts which bring the sedimentary rocks many hundred feet above sea level, and in them numerous dikes and intrusive beds of igneous rock have been seen. The most important point is that numerous seepages encircle the conical basalt hills.

Lest it should be supposed that the volcanic neck form of structure is given undue prominence in Mexican occurrences, it may be well to mention that this is described simply as *the principal quaquaversal tvpe noticed by the author* among several other Mexican types of structure. Oil fields also exist in Mexico along dikes and faults, on anticlines and probably on other kinds of domes than the one described.

Subclass II (d). Perforated Domes.—In Transylvania and Rumania the saline dome type of structure has frequently reached an exaggerated phase, owing to the facts that the dome-shaped salt masses have reached the surface of the earth and that the surrounding strata have been compressed outward

to such an extent that they stand vertical or even overturned in a circle surrounding the dome. In Rumania large oil fields are found in such structures, which are known to European geologists as "domes penetré," or perforated domes. While this type of oil-bearing structure may exist in America, it is not known to the author. It is true that in New Brunswick certain gypsum deposits appear to be of similar structure and probable origin, but they are not supposed to contain oil on account of the greater age and metamorphism of the desposits.

An evidence that interruption in structure is the concentrating factor comes from the Louisiana and Texas fields, where hundreds of wells have been drilled at a distance from the saline

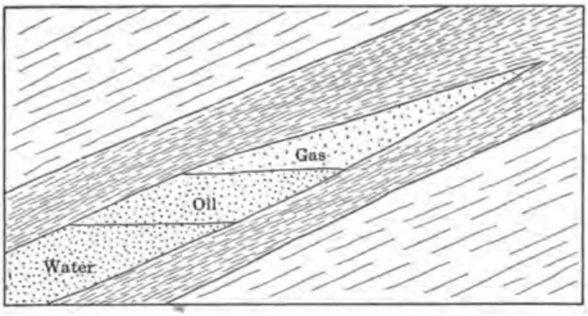


FIG. 10.—Ideal section of a pinching sand, showing the relations of gas, oil and water according to Subclass I(*e*).

domes, with a result that no oil was found. In this class of fields, as in the monoclinal and anticlinal types, the evidence seems to be that the oil has been widely disseminated in the porous strata and that it has ultimately been accumulated at favorable points where the regularity of the dip has been locally changed, or where it is interrupted by water, gas, dikes, faults, or by pinching out of strata.

Class III. In Joint Cracks.—There are a few fields in which oil occurs in the joint and cleavage fissures in shale. This is true, for instance, in the Florence field of Colorado, where, as stated by Campbell,[1] even at depths as great as 1,000 ft., the drill has sometimes struck cavities which contain oil; and the lines of the best wells are parallel to the joint crack systems. Such an occurrence of oil is unusual, but it is probable that many small

[1] *Op. cit.*, p. 86.

pools throughout the world, and some which appear to bear no definite relations to geologic structure, are in reality situated along joint cracks. In the Florence field the oil appears to be held in fissures of a broad syncline in shale.

Petroleum and solid bitumen have been noticed by various observers in traps, basalts, and other igneous rocks. An interesting instance was mentioned by Logan[1] in a greenstone dike at Tar Point, Gaspe, in the Province of Quebec. Another instance is reported by Rateau in trachite in Galicia,[2] and one in the United States, mentioned by Lakes,[3] is a volcanic dike in Archeluta County, Colorado.

Another unpublished occurrence, contributed by David T. Day, of oil, in igneous rock, refers to a boulder of vesicular basalt from Colorado, in which the vesicles were filled with oil; the latter had been sealed in by a secondary deposit of calcium carbonate, and, by removing this, it could all be extracted, and the basalt left intact. Thus the external origin of oil was deemed probable.

In the vicinity of Binny Craig, Scotland, a volcanic neck or pipe was encountered in an oil-shale working. This dike consists of trap, and contains cavities in which mineral wax, pitch or paraffin was found.[4]

These instances are not, however, in the opinion of the author, due necessarily to the oil having had an igneous origin, but may be equally well accounted for by the fact that the volcanic rock was intruded from below into the sedimentary formations which contained the oil, and consequently the volcanic rock may have absorbed large quantities of bitumen in ascending to the surface. Moreover, in an instance like that in Mexico there are a great many crevices in the volcanic necks, and these are sufficient to allow oil to enter them from the surrounding Tertiary and Cretaceous formations, and thence ascend to the surface.

Class IV. Sealed Faults.—The known examples of this class consist of some of the pools in the Los Angeles field and some of those in the Lompoc field in California, described by Arnold.[5] In these cases the highly inclined oil-sands are cut off abruptly

[1] Sir William Logan, "Geology of Canada," **1863**, pp. 400–789.

[2] *Ann. Mines*, (8), **11**, 150, 152.

[3] Arthur Lakes, "Mineral Resources of the U. S.," **1901**, p. 561.

[4] Henry M. Cadell, "Oil-shale Fields of the Lothians," *Trans. Inst. Min. Eng.*, **22**, pt. 3, 347–353.

[5] Ralph Arnold, *Bull.* **309**, *U. S. Geol. Survey*, **1907**.

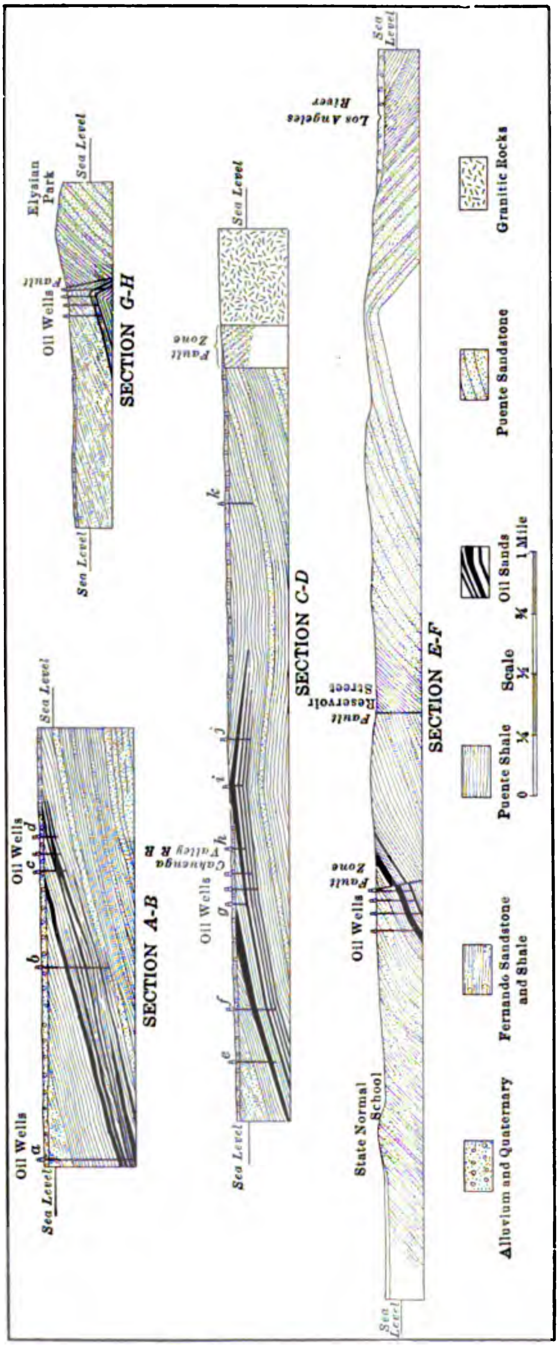


FIG. 11.—Geologic structure sections through the Los Angeles oil fields, California. (From *Bull.* No. **309**, *U. S. Geological Survey.*)

below ground by a fault, thus sealing in the oil and gas and preventing their escape to the surface. To explain the probability that such occurrences are more frequent than is known, it may be worth while to mention the fact that oil springs frequently occur along fault lines. Some of these instances exist in British Columbia and others in Gaspé, Quebec. The type is illustrated in Fig. 11. Several of the Oklahoma oil pools have recently been discovered to be associated with faults, but seepages do not exist along them.

Class V. Sealed-in by Asphaltic Deposits.—Known examples of this class, like the last, are few, but they may be perhaps exemplified by the Pitch Lake of Trinidad, near which oil is known to exist. Some of the oil found near the vein of grahamite at Ritchie mines, West Virginia, described by White,[1] may belong in this class, although these deposits are also dependent in their original accumulation upon anticlinal and synclinal structure, as in subclass I (*b*).

The source of the grahamite dike in Ritchie County, West Virginia, is believed to have been the Cairo oil-sand, at a depth of about 1,300 ft. from the surface; and there is no doubt that, now or at an earlier period, a portion of the oil was prevented from escaping by the grahamite.

Similarly, the source of the albertite dike in Albert County, New Brunswick, is believed to have been oil intruded from petroliferous strata in the Albert shales.[2] The albertite is an oxygenated hydrocarbon filling a large vertical fissure in a fine-grained shale of lower Carboniferous or Devonian age. The albertite fissure was as much as 17 ft. wide in some places and was mined to a depth of 1,300 ft. It also fills many branch veins in the wall rock.

The uintaite (gilsonite) of Utah has been shown by Eldridge to occupy a fractured zone in the central Uinta synclinal basin. There are many parallel vertical veins of gilsonite from 1/16 in. to 18 ft. in width, and from a few hundred yards to 8 or 10 miles in length, paralleling the mountains which border the basin.

To illustrate the importance of bitumen dikes in indicating petroleum and gas, it may be said that the grahamite dike of West Virginia is in the center of one of the greatest oil and gas regions in the world; that the albertite of New Bruns-

[1] I. C. White, *Bull. Geol. Soc. Am.*, **10** (1899), 277–284.

[2] Bailey, *Geol. Survey Canada*, **1876-77**, 354 *et seq.*

wick is only a few miles from the Stony Creek oil and gas field; that the uintaite dikes of Utah lead, in a general direction, toward oil which is found over the boundary in Colorado; and that oil fields are now being developed on the Island of Trinidad, on which the Pitch Lake is situated.

Class VI. Contact of Sedimentaries with Crystalline Rocks.—Aside from the occurrences of subclass II (*c*), there are no known occurrences of oil according to this type; but *gas* does exist in this way in the Provinces of Quebec and Ontario and in northern New York State, and oil presumably does in some locality. The gas is contained in the lower or arkose zone of the Potsdam sandstone, resting directly upon the underlying granite or gneiss. The deposits seem, so far as the author has been able to learn from men who know the fields, to occur on top of buried granitic knobs.

Features Common to All Types of Geological Structure.—Although there seems to be quite a discrepancy between oil fields of different subclasses, they are all similar in certain respects. In the first place, in order to hold the oil, the structures must combine several factors necessary in every oil field, *viz.:* (1) a porous or open reservoir; (2) a relatively impervious cover; and (3) some sort of geological structure by which the oil, gas and water may have been separated from each other and the oil concentrated in one locality. In anticlinal, synclinal and dome-shaped fields the structure or folding of the beds has acted as the third factor; hence we should expect to find gas nearest the crest of the anticline or dome, water farthest down dip and oil between, frequently at the locality of greatest change in dip.

In a scientific study of any oil field, for the purpose of determining its possibilities, it is necessary for the expert to distinguish the features in common with other fields from those in which the fields differ; and by a process of comparison and inference, based on the detailed observations and calculations, to draw his conclusions as to whether or not the locality is favorable for petroleum.

CHAPTER III

THE DISTRIBUTION OF PETROLEUM IN THE UNITED STATES

The General Distribution of Petroleum.—It is usual to group the oil pools of the United States in certain fields. The important of these are the Appalachian, Lima-Indiana, Illinois, Mid-Continent, Gulf Coast, California, Colorado, and Wyoming. In addition, small areas have been developed or prospected in Michigan, Utah, Missouri, Arizona, New Mexico, Alaska, etc.[1]

Such grouping not only represents the geographic arrangement convenient with regard to the accessibility of the fields to the markets, but also indicates certain more or less fundamental characteristics of the petroleums and their consequent adaptability to refining methods.[2]

Appalachian Field.—This field covers a very large area, but is no longer the most important, as it supplies but little over 10 per cent. of the country's production. It embraces all oil pools east of central Ohio, including those of New York, Pennsylvania, West Virginia, southeastern Ohio, Kentucky, and Tennessee. Nearly all of this petroleum is classed as of Pennsylvania grade, with the exception of some of the oil from Kentucky and from a few isolated pools in other states. The region in general represents the oldest oil field of the United States. Most of the pools have long since passed their prime, and in New York and Pennsylvania production is kept alive chiefly by cleaning and deepening old wells or by obtaining oil from shallow sands which were passed by as too small when the wells were first drilled. Nevertheless, no pool has been entirely abandoned as exhausted, and wells are still being pumped within a few yards of the original Drake well at Titusville, Pa. In West Virginia and on the eastern edge of Ohio are many pools long since on the wane, but the extension of territory and the discovery of new pools is still in actual progress in West Virginia, central Ohio, and Kentucky.

[1] For a consideration of the petroleum resources of the United States, see ARNOLD, *Econ. Geol.*, Dec., 1915.

[2] See p. 447 *et seq.*

Prospecting is still active in Tennessee, but so far without definitive results.

The petroliferous rocks, which range from Ordovician to Carboniferous in age, are chiefly sandstones, with a few limestones, embedded in and underlain by a great thickness of shales, while below these are probably limestone beds. The oil-bearing rocks occupy the bottom and west side of a great structural trough, within which are a number of subordinate folds. The sands range in depth from 100 to 4,000 ft.

The petroleums obtained from the Appalachian field have been of high grade, free from objectionable sulphur and from asphalt, but rich in paraffin wax. They are simplest in composition and are capable of yielding products of the highest grade at a minimum refining cost. The Kentucky and Tennessee oils are inferior to those of Pennsylvania.

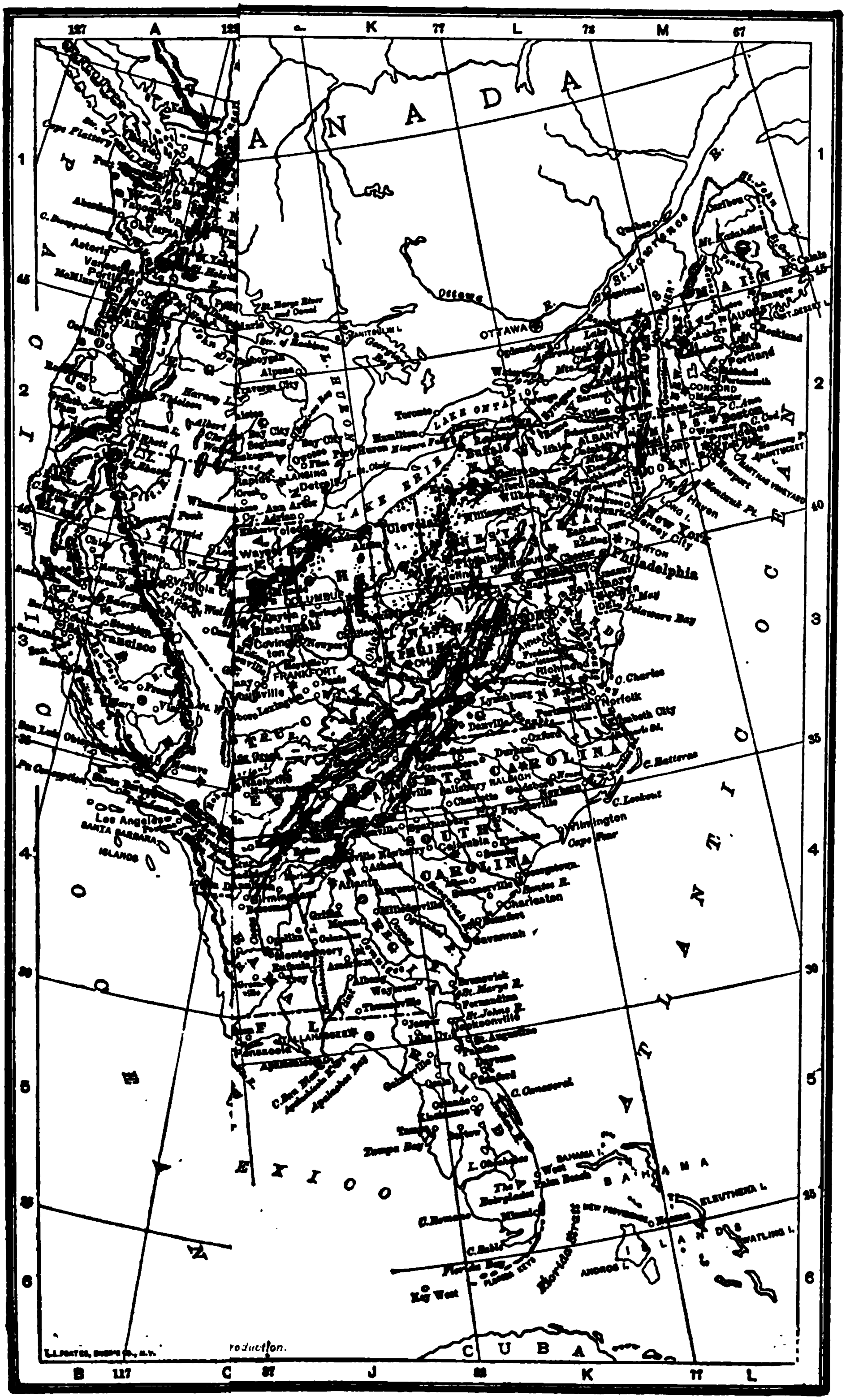
Lima-Indiana Field.—The petroleum in this field was found in Trenton limestone. It contains little asphalt, but is contaminated with sulphur compounds and requires special treatment.[1] Once freed from the objectionable sulphur compounds, the products are of high grade. The output declined in this field continuously from 1904 to 1914.[2] In 1911 oil was found in the Trenton limestone at a depth of about 1,000 ft. below the previous pools.

Illinois Field.—This field has declined since 1910. This does not presage exhaustion, but rather what may be regarded as settled production for a long time, unless the production should be increased by the discovery of new oil pools. The main portion of the field is associated with a structural feature known as the La Salle anticline, extending from the northeastern part of the State into southwestern Indiana. The petroleum is thick, asphaltic, and contains sulphur in the northern portion; but in the southern part of the field it is found at a greater depth (2,200+ ft.), is thinner, and contains little or no sulphur. Most of the Illinois oils can be refined without the employment of any special process, but only with great care and with small yields of certain of the more valuable products. The oil sands are of Carboniferous age.

Mid-Continent Field.—This field includes the oil pools of Kansas, Oklahoma, Caddo and De Soto, La., and northern

[1] See pp. 609 and 611.

[2] See p. 256.



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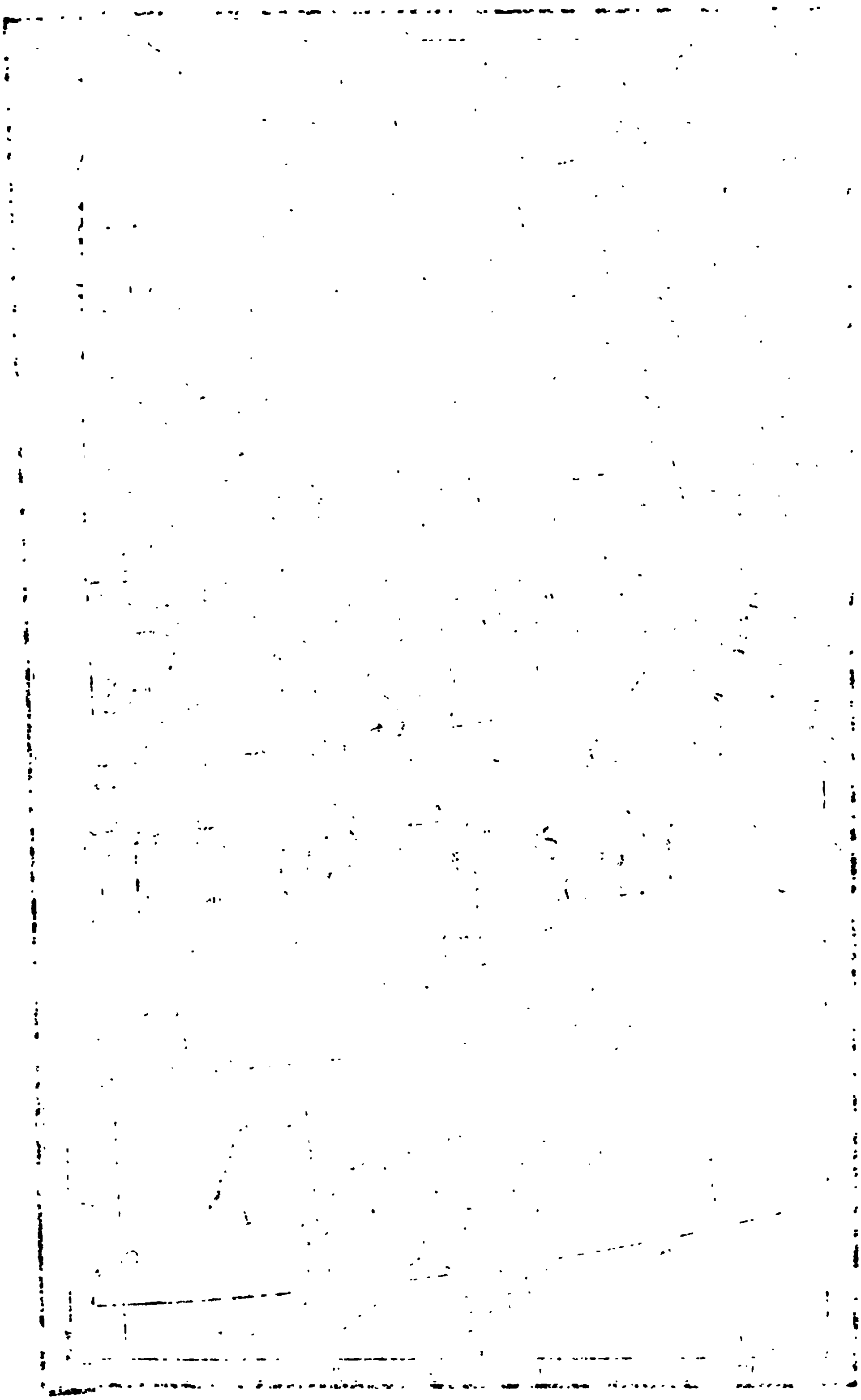


Texas. The petroleums of Kansas and Oklahoma are in general found in Carboniferous sandstones, while those of northern Texas and Louisiana occur in Cretaceous formations. Petroleums of this field vary in composition within wide limits. Most of the Kansas oils are asphaltic, but in Oklahoma petroleums of both paraffin- and asphalt-base are found. The crude petroleum of the Healdton field in Oklahoma is of lower grade than the crude oils from the Glenn pool and Cushing field, on account of the lower gasoline content and the large percentage of sulphur present which is removed with difficulty.[1] In northern Louisiana and Texas, paraffin-base petroleums, free from sulphur, predominate, but asphaltic oils of higher gravity have also been found.

Gulf Field.—Within this field are included a number of areas lying in the Coastal Plain region, the pools of southern Texas and southern Louisiana. The petroleums have been found in association with salt domes,[2] which also carry limestone and gypsum. The crude oils possess some of the characteristics of the petroleum from Baku; they are usually heavy, asphaltic and sulphurous, but occasionally lighter, nonasphaltic ones also occur. The total amount of sulphur present in the petroleums of the Gulf field is higher than that of the oils of the Mid-Continent field. The Gulf field oils are even higher in sulphur than those of the Lima-Indiana field, though the sulphur can usually be more readily removed from the former than from the latter.

California Field.—This State is now the leading producer, the output coming from a number of fields, which differ so that it is indeed difficult to generalize regarding them. The California petroleums have been usually characterized by much asphalt, although in recent years not a few lighter ones have been found. They are often in rocks that have been much disturbed.[3]

[1] See refining results given on p. 499. Cf. "Conditions in the Healdton Oil Field," Bureau of Corporations, Washington, D. C., **1915**.

[2] The similarity of the petroleum in all the pools of the Gulf field has been ascribed to the fact that it all occurs under essentially the same conditions in connection with salt domes, which are peculiar to the Gulf region. See G. D. Harris, *Science*, N. S., **27** (1908), 347; *Bull. La. Geol. Survey*, No. **7**, pp. 5–59, **1908**; *ibid.*, pp. 59–83; *Econ. Geol.*, **4** (1909), 12.

[3] On anticlinal dome structure in California oil fields, see Hager, *Western Eng.*, **3** (1913), 196. On the oil geology of California, see especially *Bull.* No. **69** of the *California State Mining Bureau*, **1914**.

The following table gives a summary of the occurrences of petroleum in the principal fields.[1]

TABLE IV.—SUMMARIZED TABLE OF OIL OCCURRENCES IN THE UNITED STATES

Field	Structure	Geologic age	Kind of rock	Kind of petroleum
Appalachian.	Geo-syncline with subordinate anticlines.	Ordovician to Carboniferous.	Mostly sandstone.	Paraffin-base[2]
Lima-Indiana.	Anticlines.	Ordovician.	Mostly limestone.	Paraffin-base.
Illinois.	Low anticlines (?).	Carboniferous.	Sandstones.	Paraffin-base and paraffin-asphalt base.[3]
Michigan.	Probably anticlines.	Silurian.	Sandstones.	Paraffin-base.
Mid-Continent.	Westerly dip with some anticlines.	Carboniferous.	Shales, sandstones, mostly.	Paraffin-, asphalt-, and paraffin-asphalt base.
Wyoming.	Usually folded.	Carboniferous to Tertiary.	Mostly sandstone.	Paraffin- and asphalt-base.
Colorado.	Folded.	Cretaceous.	Sandstone and shale.	Paraffin-base.
Gulf Coast.	Domes.	Tertiary and Cretaceous.	Dolomite and sandstone.	Mainly asphalt-base.
California.	Folded and faulted.	Tertiary.	Sandstones, shales, and conglomerates.	Mainly asphalt-base.
Alaska.	Folded and faulted.	Jurassic to Tertiary.	Sandstones and shales.	Paraffin-base.

[1] RIES and WATSON'S "Engineering Geology," **1914**, p. 570; see also RIES' "Economic Geology," 3d ed., p. 68 *et seq.*

[2] On paraffin-base petroleums, see pp. 447 and 456.

[3] On petroleums of paraffin-asphalt base, see p. 447.

The production of the various fields follows.

TABLE V.—QUANTITY, TOTAL VALUE, AND AVERAGE PRICE PER BARREL RECEIVED AT WELLS FOR PETROLEUM PRODUCED IN THE UNITED STATES IN 1912, 1913 AND 1914, BY FIELDS, IN BARRELS.[1]

Field	1912			1913		
	Quantity	Value	Average price per barrel	Quantity	Value	Average price per barrel
Appalachian	26,338,516	$42,818,384	$1.626	25,921,785	$63,708,981	$2.458
Lima-Indiana	a 4,925,906	a 4,794,783	0.932	4,773,138	6,588,068	1.380
Illinois	28,601,308	24,332,605	0.851	23,893,899	30,971,910	1.296
Mid-Continent	65,473,345	45,300,669	0.692	84,920,225	80,767,758	0.951
Gulf	8,545,018	6,344,173	0.742	8,542,494	7,993,997	0.936
California	b 87,272,593	b 39,624,501	0.454	97,788,525	45,709,400	0.467
Colorado and Wyoming	1,778,358	998,131	0.561	2,595,321	1,362,011	0.525
Other fields	....	....	......	c 10,843	c 19,265	1.227
Total	222,935,044	$164,213,247	$0.737	248,446,230	$237,121,388	$0.954

a Includes Michigan. b Includes Alaska. c Includes Alaska, Michigan, Missouri, and New Mexico.

Field	1914		
	Quantity	Value	Average price per barrel
Appalachian	24,101,048	$45,239,201	$1.877
Lima-Indiana	5,062,543	5,983,356	1.182
Illinois	21,919,749	25,426,179	1.160
Mid-Continent	97,995,400	78,671,902	0.803
Gulf	13,117,528	8,844,104	0.674
California	99,775,327	48,066,096	0.482
Colorado and Wyoming	3,783,148	1,880,086	0.497
Alaska, Michigan and Missouri	7,792	14,291	1.834
Total	265,762,535	$214,125,215	$0.806

[1] Mineral Resources of the United States, **1913**, ii, 145; *The Mineral Industry*, **23** (1915), 553; *Mineral Resources of the United States*, **1914**, ii, 906.

THE GEOGRAPHICAL DISTRIBUTION OF PETROLEUM IN THE UNITED STATES

Alabama	There is a show of oil in wells in the northwestern part of Alabama, but there are no producing wells. In the Tennessee valley, in the northern part of the State, there are tar-springs, oozings, and other indications of the presence of petroleum. Two wells were completed in 1912; both were dry. There were no drilling operations in 1913. In 1914, unsuccessful efforts were made to discover oil in Chilton and Jackson counties. On oil prospects in Alabama, see P. BYRNE, *Proc. Eng. Assn. South*, **21** (1910), 167. On the Fayette gas field, see M. J. MUNN, *Bull. U. S. Geol. Survey*, No. **471** (1912).
Alaska	Petroleum occurs in Alaska at Cape Yakthe; near the mouth of Copper River, in the Controller Bay district; on the west shore of Cook Inlet; and in the region of Cold Bay. Some well drilling has been conducted in the Cook Inlet region; both petroleum and gas were found. Three wells were drilled in the Cold Bay region in 1903; in one a heavy oil was encountered. Wells have also been drilled at Katalla, in the Controller Bay district; oil was found in some quantity (see THOMPSON, *Min. Sci. Press*, **105** (1912), 169). In 1914, the Katalla field yielded a small output of petroleum. On the petroleum deposits of Alaska, see A. H. BROOKS, *Trans. Am. Inst. Min. Eng.*, **35** (1905), 376; *Bull. U. S. Geol. Survey*, No. **394**, pp. 172–207 (1910); H. HÖFER, *Petroleum*, **5** (1910), 741; G. C. MARTIN, *Bull. U. S. Geol. Survey*, No. **225**, pp. 365–382 (1904); *Bull. U. S. Geol. Survey*, No. **250** (petroleum fields of the Pacific coast of Alaska); *Bull. U. S. Geol. Survey*, No. **259**, pp. 128–139 (1905); W. T. PROSSER, *Eng. Min. J.*, **91** (1911), 1098; *Mines and Minerals*, **31** (1911), 731 (Katalla field); P. C. STOESS, *Min. Sci. Press*, **87** (1903), 65 (Kayak field); and *Ann. Rept. Gov. Alaska to Secy. of Interior*, **1903**. See especially, however, *Bull. U. S. Geol. Survey*, No. **467** (1911) by W. W. ATWOOD; and BROOKS, *Bull. Am. Inst. Min. Eng.*, 1915, No. **98**, 199.
Arizona	Petroleum is said to be found in Mohave County (sandstone saturated with petroleum); in traces in water wells at Douglas in Cochise; and in the Mammoth District in Pinal. One well was completed in 1912; it was a dry hole. A test well was begun in 1914, in Tonto Basin, Gila County. Asphalt has been reported to occur on the Great Colorado Plateau.
Arkansas	In four counties in Arkansas five wells were drilled in 1913 in search of petroleum, but with no result (dry). Fayetteville,

	Washington County, has produced petroleum, which occurs in a shale of the Carboniferous limestone series. Asphalt is said to occur in Madison and Scott counties. Natural gas has been obtained in Sebastian County since 1902. Test wells for petroleum were begun in 1914, at or near Ozark and Meg, Franklin County; Paris, Logan County; Hope, Hempstead County; and De Queen, Sevier County.
California	Petroleum is the most important mineral product of California, the leading State in the 1914 production of oil. The principal fields in order of importance are the Midway-Sunset, Coalinga, Whittier-Fullerton, Kern River, Lost Hills-Belridge, Lompoc-Santa Maria, McKittrick, Los Angeles, Ventura County-Newhall, Summerland, and Watsonville. There are also numerous indications of oil in Devils Den, Kreyenhagen, and Kettleman Hills districts, southern San Luis Obispo County; Parkfield and Loneoak districts, and west of Bradley, western Monterey County; San Antonio River district, southern Monterey County; Sargent and Moody Gulch districts, Santa Clara County; western San Mateo County; Vallecitos district, San Benito County; Livermore district, Alameda County; western Contra Costa County; Colusa County; and in southern Humboldt County. The production of the State amounted to 99,775,327 bbl. in 1914. On the oil prospects of the Cantua-Panoche region, Cal., see R. ANDERSON, *Bull. U. S. Geol. Survey*, No. **431**, pp. 58–87 (1910). On fields, see M. ANGEL, *10th Ann. Rept. State Mineral. Cal.*, **1890**, 219 (Kern County); *ibid.*, 345 (Monterey County); *ibid.*, 567 (San Luis Obispo County); R. ARNOLD, *Bull. U. S. Geol. Survey*, No. **285**, pp. 357–61 (1906) (Salt Lake field); *ibid.*, No. **309**, pp. 138–198 (1907) (Los Angeles district); *ibid.*, No. **321** (1907) (Summerland district); *ibid.*, No. **340**, pp. 339–342 (1908) (Miner Ranch field); *Compt. rend. Cong. internat. Pétrole, sess.* 3, **2** (1910), 365 (Santa Maria district); C. BARLOW, *Petrol. Rev.*, **6** (1902), 16 (Kern County fields); and C. T. DEANE, *Petrol. Rev.*, **7**, (1902), 133 and 641. On oil prospects of Cuyama Valley, Cal., see W. A. ENGLISH, *Bull. U. S. Geol. Survey*, No. **621-M.** On the McKittrick field, see W. G. YOUNG, *Eng. Min. J.*, **71** (1901), 30; and on the Coalinga field, see *ibid.*, 403. On petroleum in northern Cal., see A. H. WEBER, *7th Ann. Rept. State Mineral. Cal.*, **1887**, 193. On the petroliferous formations of Central Valley, Cal., see W. L. WATTS, *Bull. Cal. State Min. Bur.*, No. 3, **1894**; see also *Min. Sci. Press*, **79** (1899), 144, 172. P. W. PRUTZMAN has discussed "Petroleum in California," in *Petrol. Rev.*, **9** (1903), 331, 351, 395, 424 and 435; as has E. O'NEILL in *Compt. rend. Cong. internat. Chem. appl., sess.* 5, **2** (1904),

	760. On California petroleum in 1914, see REQUA, *Eng. Min. J.*, Jan. 16, **1915**, 139. For a full account of the petroleum industry of California, see *Bull.* No. **69**, *Cal. State Min. Bur.*, **1914**. On petroleum in southern California, see the special bulletin by P. W. PRUTZMAN, issued by the same Bureau in 1913.
Colorado	The Colorado oil fields are as follows: Boulder County, Boulder oil field, 3 miles northeast of Boulder; high-grade light illuminating oil. Fremont County, south of Florence; field 10–20 sq. miles. Mesa County, small wells near De Beque. Routt County, Yampa field; used as lubricant. Rio Blanco County, Rangely oil district. Petroleum has been found also in Archuleta, Pueblo, Crowley, Moffat and Garfield counties. The total Colorado production amounted to 222,773 bbl. in 1914. Oil-shales occur in Delta and Garfield counties; extensively developed, geologically, constituting the greater part of the rocks of the Green River formation (Eocene). In the Book Cliffs, the richer rock occurs in bands, about 50 in number, from 2 to 15 ft. thick. Destructive distillation gives from 15 to 35 per cent. of condensed hydrocarbons, and 10 to 20 per cent. of gas. These shales are a prospective source of lubricating oil. On oil-shales of northwestern Colorado, see WOODRUFF and DAY, *Bull. U. S. Geol. Survey*, No. **581**, 1914. For the histories of the Colorado oil regions, see LAKES, *Mines and Minerals*, **23** (1903), 399. The geology of the White River district is described by F. M. ENDLICH in *Ann. Rept. U. S. Geol. Survey Territories*, **10** (1878), 61–131, wherein, on pp. 135–159, is given a catalogue of Colorado minerals. On the oil fields of Colorado, see N. M. FENNEMAN, *Bull. U. S. Geol. Survey*, No. **213**, pp. 322–32 (1903) (Boulder field); *ibid.*, No. **225**, pp. 383–91 (1904) (structure of Boulder field); *ibid.*, No. **260**, pp. 436–40 (1905) (Florence field); H. S. GALE, *ibid.*, No. **350** (1908) (Rangely district); A. LAKES, *Mines and Minerals*, **19**, 477; **21**, 981; **22**, 107 (prospects); *Bull. Sch. Mines Colo.*, **1** (1901), 221 (geology); *Mines and Minerals*, **22** (1902), 150 (Rio Blanco County); *Mining Sci.*, **62** (1911), 235, 311 (general), 341 (Boulder field), 367 (Florence field); and J. S. NEWBERRY, *Proc. Am. Assn.*, **37** (1887), 186 (general).
Connecticut	While bitumen is widely distributed in the amygdaloidal trap rocks traversing the Trias of Connecticut at Hartford, Farmington, New Britain, Middleton, Meriden, and Southbury, and elaterite occurs at Woodbury, petroleum has not

	been found. See J. G. PERCIVAL, "Report on the Geology of the State," New Haven, **1842**; and *Am. J. Sci.*, (3), **16**, 130 (on "indurated bitumen.")
Delaware	The occurrence of bituminous substances has not been reported.
District of Columbia	None of the bituminous substances occurs commercially.
Florida	It is said that the Eocene beds of Juliette in Marion County are petroliferous. Pockets of gas of no commercial value were penetrated in a test well begun during 1914, near Kissimmee, Osceola County.
Georgia	Petroleum has been reported in the Trenton Limestone of Dalton, Whitfield County; also in Floyd County, near Rome. There is little probability of commercial production. A test well was begun in 1914 near Waycross, Ware County.
Idaho	It has been reported that a fuel oil was found in Neogene lacustrine deposits along the Snake River, near Warm Springs Ferry. On oil prospects near Payette, Idaho, see C. W. WASHBURNE, *Bull. U. S. Geol. Survey*, No. **431**, pp. 22–55 (1911).
Illinois	In the shallow fields of southeastern Illinois, the Clark, Cumberland, Coles, and Edgar County fields (shallow oil-sand territory) showed a very low but steady yield of oil in 1912 and 1913. Like the shallow fields, the Crawford County area, with its 900-ft. sands, was rapidly developed and drained, and is maintaining a low but steady yield. Lawrence County is the richest oil-producing area in the State. There are seven sands from 450 to 1,985 ft. in depth that produce large quantities of high-grade oil. There are at present 36 producing wells with a daily production of about 700 bbl. in Wabash County. In south-central and western Illinois, the Carlyle pool, 3 miles northwest of Carlyle in Clinton County, has shown a steady decline in the past two years. The Sandoval pool in Marion County, had, in 1913, 112 producing wells. Both the Sandoval and the Carlyle pools have been profitable because of their continued yield. The Carlinville pool, 2 miles south of Carlinville, in Macoupin County, yielded about 200 bbl. per day during 1913. In 1913, Illinois produced 23,893,899 bbl. of petroleum; 1,363 oil wells were drilled in that year. The sharp decline in production, beginning in 1912, appears to correspond with the decrease in new development in the deep Lawrence County pools. The opening of new fields would probably

reverse the situation. In 1914, the production amounted to 21,919,749 bbl. valued at $25,426,179.

The southeastern Illinois oil field has been described by H. F. BAIN, *Min. Sci. Press*, **92** (1906), 326; in a later paper BAIN describes the various Illinois fields (*idem*, **99**; 153). On the petroleum resources of Illinois, see R. S. BLATCHLEY, *Bull. Geol. Survey Ill.*, No. **16**, 1911; *Petrol. Rev.*, **25** (1911), 101; *Nat. Gas J.*, **5** (1911), No. 3, 17; and *Eng. Min. J.*, **91** (1911), 92; **93** (1912), 95. On the petroleum industry of southeastern Illinois, see BLATCHLEY, *Bull. Geol. Survey Ill.*, No. **2**, 1906. For an account of the Carlyle field, see E. W. SHAW's report issued by the University of Illinois in 1912; and H. A. WHEELER, *Eng. Min. J.*, **92** (1911), 63; see *ibid.*, 355, for a description of the various fields in the State. On Illinois petroleum in 1914, see BLATCHLEY, *Eng. Min. J.*, Jan. 16, **1915**, 136. BLATCHLEY has also discussed oil in Bond, Macoupin and Montgomery counties, the oil fields of Crawford and Lawrence counties, and the Plymouth fields in special reports of the State Geol. Survey, Ill., **1914**.

Indiana

There are producing wells in the following counties: Adams, Blackford, Daviess, Delaware, Gibson, Grant, Greene, Hamilton, Huntington, Jay, Perry, Pike, Randolph, Sullivan, Vigo, and Wells. The production in 1913 amounted to 956,095 bbl. The petroleum industry of Indiana developed rapidly between the years 1891 and 1904, but the production declined steadily from 1905 to 1914, when 1,335,456 bbl. were produced.

On the petroleum fields of Indiana, see EDW. BARRETT, *Rept. Dept. Geol. Nat. Res. Ind.*, **1914**; A. C. BENEDICT, *17th Ann. Rept. Geol. Ind.*, **1892**, 306–325; W. S. BLATCHLEY, *Ann. Rept. Ind. Geol. Survey*, **31** (1907), 559–593 (Princeton field); *ibid.*, **20** to **33** (industry); J. COLLETT, *Ann. Rept. Geol. Survey Ind.*, **4** (1872), 291–337; *ibid.*, **5** (1874), 315–382 (Knox County); *ibid.*, **8, 9, 10** (1879), 291–522 (Harrison and Crawford counties); M. N. ELROD and A. C. BENEDICT, *Ann. Rept. Geol. Survey Ind.*, **17** (1892), 192 (Wabash County); *ibid.*, **19** (1894), 17 (Cass County); M. L. FULLER, *Bull. U. S. Geol. Survey*, No. **213**, pp. 333–335 (1903) (southwestern Indiana); S. S. GORBY, *Ann. Rept. Geol. Survey Ind.*, **15** (1886), 198; **16** (1889), 165; and C. K. MACFADDEN, *Petrol. Rev.*, **4** (1901), 270, 305, 322 and 345 (general survey).

Iowa

Petroleum has nowhere been discovered in commercial quantity, but rather widely disseminated, as shown by traces in wells; it has been found near Fort Madison, Lee County, in very

	small quantity. Natural gas has been found in Dallas, Louisa, Hamilton, Muscatine, Polk, Sac, and Story counties. On the geology of Polk County, Iowa, see H. F. BAIN, *Rept. Iowa Geol. Survey*, **7** (1897), 263–412; and on the geology of Guthrie County, Iowa, see also BAIN, *ibid.*, 413–487. On Dallas County, Iowa, see A. G. LEONARD, *Ann. Rept. Iowa Geol. Survey*, **8** (1898), 51–118. Two reports by S. CALVIN, in *Ann. Rept. Iowa Geol. Survey*, **11** (1901), 9–30; **12** (1902), 11–27, refer to the occurrence of petroleum in Iowa.
Kansas	There are producing wells in Allen County (vicinity of Moran and Humboldt); Chautauqua County (Sedan, and southern part); Miami County (high-grade oil, Paola); Montgomery County (Coffeyville, Wayside, and elsewhere in Bolton field); Neosho County (Chanute); Wilson County (vicinity of Toronto); and in Franklin and Woodson counties. Petroleum occurs in numerous other localities in the State. 2,375,029 bbl. of petroleum were produced in 1913, and 3,103,585 bbl. in 1914. For the history of Kansas oil development, see L. L. WITTICH, *Mines and Minerals*, **32** (1912), 384. The oil fields of Kansas have been described by E. ALBRECHT, *Petroleum*, **1** (1906), 640; P. DOUGLAS, *Petrol. World*, **3** (1906), 105 and 204; P. DVORKOVITZ, *Petrol. Rev.*, **11** (1904), 403, 423, 425, 443, 444, 463 and 464; E. HAWORTH, *Proc. Am. Assn.*, **43** (1894), 229; *Univ. Geol. Survey Kan.*, **1** (1896), 232; *Eng. Min. J.*, **72** (1901), 397; *ibid.*, **74** (1902), 477 (Chanute fields); *ibid.*, **79** (1905), 42; *ibid.*, **89** (1910), 132; *ibid.*, **91**, 91; *ibid.*, **93** (1912), 95; and HAWORTH *et al.*, *Kansas Univ. Geol. Survey*, **9** (1908), pp. 586 (a valuable general report). For a general survey, see W. H. HEYDRICK, *Mining Mag.*, **10** (1904), 363–75; and WALKER and BOHNSTENGEL'S "Western Kansas Fuels; Coal, Oil, Gas" (University of Kansas, **1913**).
Kentucky	Kentucky has the following oil-producing areas: Barren County (near Glasgow); Bath County; Breathitt County (Frozen Creek); Cumberland County (near Burkville); Estill County (near Irvine); Floyd County (Right Beaver, Salt Lick, and Middle creeks, near Prestonburg); Knox County (vicinity of Barbourville); Lawrence County (Busseyville); Logan County (Diamond Springs); Menifee County; Morgan County (Caney and West Liberty); Ohio County (near Hartford); Rowan County (Triplet Creek); Wayne County (number of wells); Webster County (Lebree); Whitley County (near Williamsburg); Wolfe County (near Campton). Oil shows reported in Allen, Boyd, Breckenridge,

	Caldwell, Carroll, Carter, Christian, Clark, Clinton, Harrison, Hart, Jefferson, Johnson, Knott, Lawrence, McLean, Magoffin, Martin, Meade, Montgomery, Oldham, Pike, Pulaski, Rockcastle, Russell, and Warren counties. 524,568 bbl. of petroleum were produced in Kentucky in 1913; it came mainly from a considerable number of small wells, most of them old, in Wayne County. 502,441 bbl. constituted the 1914 production. On the oil field of Barren County, Ky., see M. FISCHER, *Eng. Min. J.*, **49** (1890), 197; on the oil-sands of the State, see J. B. HOEING, *Bull. Ky. Geol. Survey*, No. **1**, 1905; on the geology of the lands on Paint Lick Fork of Sandy River in eastern Kentucky, see J. P. LESLEY'S "Petroleum," Philadelphia, **1865**; and on the east Kentucky oil region, see J. P. LESLEY, *Proc. Am. Phil. Soc.*, **10** (1865), 33, 187. On the Campton and Knox pools, see M. J. MUNN, *Bull. U. S. Geol. Survey*, No. **471** (1912). On the Ragland oil field, see M. J. MUNN, *ibid.*, No. **531** (1913). For a reconnaissance of the oil fields of Wayne and McCreary counties, see M. J. MUNN, *ibid.*, No. **579** (1914). For a recent discussion of oil possibilities in Kentucky, see FOHS, *Bull. Am. Inst. Min. Eng.*, **1915**, No. **99**, 621.
Louisiana	Petroleum is produced in Caddo Parish (Caddo field is an important producer); Calcasieu Parish (Vinton gushers in 1911); numerous wells 6 miles northeast of Jennings in Quaternary and Miocene beds; Cameron Parish (small quantity of oil from wells on Hackberry Islands); Iberia Parish (small quantity in wells at Bayou Bouillon, 30 miles northeast of New Iberia); St. Landry Parish; Pine Prairie (gusher, 1912); St. Martin Parish (in coarse shallow sands at Breaux Bridge, Anse-la-Butte district). In 1913, development occurred near Mansfield in De Soto Parish. 12,498,828 bbl. of petroleum were produced in the Jennings, Welsh, Anse-la-Butte, Vinton, and Caddo districts in 1913, when 437 oil wells were drilled in Louisiana. In 1914, Louisiana produced 14,309,435 bbl. of petroleum. On occurrences of petroleum in Louisiana, see DAY, OLIPHANT, and GREER, *Manuf. Record*, **1910**; HARRIS, PERRIN, and HOPPER, *Bull. Geol. Survey La.*, No. **8**, 1911 (Caddo field); G. D. HARRIS, *Rept. Geol. Survey La.*, part vi, pp. 265–75, **1902**; and *Bull. U. S. Geol. Survey*, No. **429** (1910) (summary of occurrences). On the geology, see E. W. HILGARD, *Am. J. Sci.*, (2), **47** (1869), 77 (lower Louisiana); *ibid.*, **48** (1869), 331 (summary of results); and "Supplementary and Final Report of a Geological Reconnaissance of the State of Louisiana," New Orleans, **1873**. For a recent account

	of oil in Louisiana, see HAZLETT, *Eng. Min. J.*, Jan. 16, **1915**, 137.
Maine	No reported occurrences of bitumen in any of its forms.
Maryland	Retinasphalt occurs in the Eocene beds of Cape Sable; no other bitumen has been reported. In 1914, near Parsonburg, Wicomico County, a well was drilled to a reported depth of 500 ft. and abandoned in quicksand.
Massachusetts	No occurrences of any of the forms of bitumen have been reported.
Michigan	Petroleum occurs near Port Huron, Saginaw, and Allegan. In 1912, oil was struck in the city of Saginaw; much excitement resulted, but the subsequent wells were failures. There was a slight production in 1913 from the small wells in St. Clair County, where, as in Sanilac County, oil and gas are yielded by the Devonian. The small production of petroleum credited to Michigan in 1914 consisted of natural lubricating oil from a few wells near Port Huron. On asphalt in Delta County, Mich., see A. C. LANE, *Eng. Min. J.*, **73** (1902), 50; and on prospects for oil in Michigan, see LANE, *Ann. Rept. Mich. Geol. Survey*, **1901**, 211–237; *Mich. Miner*, **9** (1907), Nos. 4 and 5. For a description of the "Baker Tract," see WINCHELL'S "The Oil Region of Michigan," Detroit, **1864**; cf. WINCHELL'S "Geological Report on Certain Oil Lands Lying in the Counties of Sanilac and St. Clair, Mich.," Detroit, **1865**. The occurrence of oil in Michigan is fully considered by SMITH, *Mich. Geol. and Biol. Survey*, **1914**.
Minnesota	Temporary discharges of natural gas have been reported from various counties in the State. On natural gas in Minnesota, see N. H. WINCHELL, *Bull. Geol. Survey Minn.*, **1889**, No. **5**. It has been said that oil is found in the Trenton and lower divisions.
Mississippi	Petroleum has not been found commercially in this State, although tests have been drilled in Covington, Jefferson, and Lauderdale counties.
Missouri	A small quantity of petroleum occurs in shallow wells in northern Cass and southern Jackson counties; it has been obtained in Bates County; it was discovered at shallow depths at Swart in Vernon County in 1913; and, in 1913, a shallow well was drilled in Adair County which yielded a showing

	of oil, but no production. Commercial production of petroleum was limited to Jackson County in 1914. On the geology of northwestern Missouri, see G. C. BROADHEAD, *Rept. Geol. Survey Mo.*, **1872**, pt. ii, 1–213 and 290–402; on Jasper County, see *ibid.*, **1873–4**, 77–96. BROADHEAD also described the occurrence of bitumen in Missouri in *Trans. Acad. Sci. St. Louis*, **3** (1875), 224–226. Oil boring in Missouri was described by ROBINSON in *Eng. Min. J.*, **4**, 297; **5**, 261 (1868); and SHUMARD gave an account of the oil springs of Missouri in *Trans. Acad. Sci. St. Louis*, **2**, (1866), 263.
Montana	Petroleum occurs in eastern Cascade County; in the Porcupine Dome, Rosebud County, and in the northwestern part of Teton County; there is no production, and only a few test wells have been drilled. Oil-shales of reported commercial value occur 60 miles northeast of Helena. Natural gas is found near Havre. On the probable oil in Montana, see ROWE, *Eng. Min. J.*, Apr. 10, **1915**, 647; and C. F. BOWEN, *Bull. U. S. Geol. Survey*, No. **621F** (1915).
Nebraska	It was reported in 1903 that petroleum occurred in very small quantities in Rock and Brown counties. See E. H. BARBOUR, *Nebraska Geol. Survey*, **1**, Lincoln, **1903**.
Nevada	Oil-shale occurs near Elko on the property of C. A. CATLIN, and a high-paraffin oil, resembling the distillate thereof, has been reported as exuding from Eocene shales, half a mile south of Elko. Bitumen is found in the andesites of the eastern shore of Lake Tahoe, and asphalt occurs on Trout, Pine and Willow creeks in Eureka County. See ROBERT ANDERSON, *Bull. U. S. Geol. Survey*, No. **380**, pp. 283–285 (1909); No. **381**, pp. 475–493 (1910) (on oil prospects in the Reno Region and in Lyon County); and I. MACFARLAND, *Proc. Am. Min. Cong.*, **12** (1909), 418 (on the development of petroleum in Nevada).
New Hampshire	No reported occurrences of the forms of bitumen.
New Jersey	The occurrence of petroleum has not been reported. Bitumen, however, is present in the amygdaloidal intrusives of the Triassic beds of Newark, asphalt occurs in small amounts in the "ash-marl" of Vincent-town, and ozokerite is found in the Cretaceous brick-earth of South Amboy.

New Mexico	Petroleum occurs near Artesia, Chaves County; south of Raton, Colfac County; at Dayton, Eddy County; in the Seven Lakes field, McKinley County; and in Bernalillo County. Considerable development work has been done in Eddy County. On petroleum near Dayton, N. Mex., see G. B. RICHARDSON, *Bull. U. S. Geol. Survey*, No. **541** (1912).
New York	The productive horizon is in Upper Devonian sandstones. The principal producing fields are Allegany County (Andover, Bolivar, Wirt, and other towns) and Cattaraugus County (Allegany, Carrollton, and Olean townships). Erie and Steuben counties are minor producers. 948,191 bbl. of petroleum were produced in New York in 1913, while the 1914 production amounted to 938,974 bbl. On petroleum in New York State, see C. A. ASHBURNER, *Trans. Am. Inst. Min. Eng.*, **14** (1886), 419; **16** (1888), 906; I. P. BISHOP, *Ann. Repl. N. Y. State Mus.*, **51** (1899), ii, 9–63 (in western New York); *ibid.*, **53** (1901), i, R., 105–34 (in southwestern New York); E. ORTON, *Bull. N. Y. State Mus.*, **6** (1899), i, appendix i, 395–526; D. A. VAN INGEN, *Bull. N. Y. State Mus.*, **3** (1896), 558; and H. E. WRIGLEY, *Trans. Am. Inst. Min: Eng.*, **10** (1882), 354 (amount of oil remaining). On operations during 1911, see D. H. NEWLAND, *Bull. N. Y. State Mus.*, **161**, (1912).
North Carolina	Beds of a petroliferous character occur at several horizons in basins containing coal beds, of Mesozoic and probably Triassic age. These basins are the Dan River area, on the Virginia and North Carolina border, and the Oxford-Wadesborough field, obliquely traversing almost the entire width of North Carolina. The deposits of petroleum are worthy of no attention at present.
North Dakota	Natural gas has been obtained from Cretaceous rocks in Bottineau and Lamoure counties, but no petroleum has been reported. See A. G. LEONARD, *Bull. U. S. Geol. Survey*, No. **431**, pp. 7–10 (1911). In 1914, a deep test near Gettysburg, Potter County, proved barren of oil or gas.
Ohio	There are three important fields: the Lima, or northwestern, the central, and the southeastern. Large production from Allen, Auglaize, Hancock, Lucas, Mercer, Ottawa, Sandusky, Seneca, Van Wert, and Wyandot counties of the northwestern field. Athens, Coshocton, Fairfield, Holmes, Knox, Lorain, Muskingum, Perry, and Vinton counties of the central field contain producing wells. Large production

	from wells in the southeastern field in Ashland, Belmont, Carroll, Columbiana, Guernsey, Harrison, Hocking, Jackson, Jefferson, Licking, Monroe, Morgan, Noble, and Washington counties. The production of petroleum amounted to 8,781,468 bbl. in 1913, during which year 1,246 oil wells were drilled in central and southeastern Ohio, and 873 in the Lima district. The 1914 production was 8,536,352 bbl. For an early description of the oil regions of Ohio, see J. H. A. BONE's "Petroleum and Petroleum Wells," New York, **1865.** On the fields, see especially the following reports by J. A. BOWNOCKER: *Ohio Nat.*, **1** (1901), 49 (Corning field); *J. Geol.*, **10** (1902), 822 (oil-producing rocks); *Bull. Geol. Survey Ohio*, No. **1,** 1903 (occurrence); *ibid.*, (4), No. 12, 1910 (Bremen field); and *Econ. Geol.*, **6** (1911), 37 (Clinton sand as a source). See also J. S. NEWBERRY, *Ohio Agric. Rept.*, **1859,** 605 (rock oils of Ohio); *Can. Nat.*, **5** (1860), 325 (oil wells of Mecca); and *Repts. Geol. Survey Ohio*, vols. **1–3,** 1873, 1874, 1878. On the geology, see E. ORTON, *Proc. Am. Assn.*, **30** (1881), 167 (Berea Grit); *ibid.*, **33** (1885), 397 (horizons); and *ibid.*, **34** (1886), 202 (sources). On the structure of the Berea oil sand, see D. D. CONDIT, *Bulls.* **621–N** and **621–O,** *U. S. Geol. Survey*.
Oklahoma	The most productive areas are in northeastern Oklahoma at or near Bartlesville, Copan, Dewey, Glenn Pool, Hamilton, Henryetta, Ramona, Red Fork, Skiatook, Tamaha, and Tulsa. Important producers are at Coodys Bluff-Alluwe field; Carter County (Healdton and Wheeler); Marshall County (Mahill); Osage County (Hominy); Muskogee County (Muskogee); Pawnee County (Cleveland). Small quantity is found in Comanche County (at Lawton); Creed County (near Mounds); Greer County (Granite); Kiowa County (Gotebo); Mayes County (spring near Adair). 63,579,384 bbl. of petroleum were produced in the State in 1913. 6,965 oil wells were drilled during that year, which was marked by the development in the Cushing pool and the opening up of the Healdton field. In 1914, 73,631,724 bbl. constituted the production. For an account of the oil development in northcentral Oklahoma, see R. H. WOOD, *Bull. U. S. Geol. Survey*, No. **531** (1913); and L. C. SNIDER's "Petroleum and Natural Gas in Oklahoma," **1913.** On the oil fields of Oklahoma, see C. N. GOULD, *Eng. Min. J.*, **84** (1907), 259; *Bull. Okla. Geol. Survey*, No. **1,** 1908; L. L. HUTCHISON, *Bull. Okla. Geol. Survey*, No. **2,** 1911; J. A. TAFF and W. J. REED, *Bull. U. S. Geol. Survey*, No. **381,** pp. 504–13 (1910) (Madill oil pool); L. L. WITTICH, *Mines and Minerals*, **32** (1911), 291; and E. G. WOODRUFF, *Science*, N. S., **23** (1906), 621 (region around Cleveland, Pawnee County). On the Grand-

	field district, see M. J. MUNN, *Bull. U. S. Geol. Survey*, No. **547** (1914); and on the Glenn Pool, see C. D. SMITH, *idem*, No. **541** (1912). The Cushing field has been considered fully by BUTTRAM in *Bull.* No. 18, *Okla. Geol. Survey*, **1914**; and the Ponca City field by OHERN in a *bulletin* issued by the same Survey in 1912. On the Healdton oil field, see *Bull. U. S. Geol. Survey*, No. **621–B** (1915), 1. For a geological description of the Healdton pool, see GARDNER, *Econ. Geol.*, **10** (1915), 422.
Oregon	It has been reported that petroleum deposits of considerable extent exist in Maheur and Crook counties; but there has been no extensive development. See C. W. WASHBURNE, *Bull. U. S. Geol. Survey*, No. **431**, pp. 22–57 (1911); *Bull.* No. **590** (oil prospects of northwestern Oregon); and H. M. PARKS, *Oregon Agr. Coll., Coll. Bull.*, Extension Series 5, No. **2**, 1912 (resources).
Pennsylvania	Petroleum is produced in Allegheny, Armstrong, Beaver, Bradford, Butler, Clarion, Crawford, Elk, Fayette, Forest, Greene, Lawrence, McKean, Mercer, Tioga, Venango, Warren, Washington, and Westmoreland counties. All of the different pools have long passed their prime, but they differ in their stages of exhaustion. The pools in Venango County, in the Bradford Area, include those which originated the petroleum industry in the United States. The wells in southwestern Pennsylvania have been drilled more recently. 7,963,282 bbl. of petroleum were produced in Pennsylvania in 1913, when 3,420 oil wells were drilled in the State. The production increased to 8,170,335 bbl. in 1914. On the oil regions of Pennsylvania, consult the following: F. M. L. GILLELEN'S "The Oil Regions of Pennsylvania," Pittsburgh, **1864**; C. A. ASHBURNER, *J. Frank. Inst.*, **105** (1878), 225 (oil-sands); *Trans. Am. Inst. Min. Eng.*, **2** (1878), 316 (Bradford district); *Second Geol. Survey Pa., R.*, **1880** (McKean County); J. H. A. BONE'S "Petroleum and Petroleum Wells," New York, **1865** (early account of regions); C. BUTTS, *U. S. Geol. Survey, Fol.* **125, 1905** (Rural Valley), *Fol.* **172, 1910** (Warren), *Fol.* **115, 1904** (Kittanning); M. R. CAMPBELL, *U. S. Geol. Survey, Fol.* **82, 1902** (Uniontown), *Fol.* **94, 1903** (Brownsville); J. F. CARLL, *Second Geol. Survey Pa.*, **1877** (oil-well records); *ibid.*, **13-15**, 1880–1890 (geology of regions); H. M. CHANCE, *ibid.*, **V**, 1879, and **VV**, 1880 (Butler and Clarion counties); F. G. CLAPP, *Bull. U. S. Geol. Survey*, Nos. **285** (362–66) and **300**; CONE and JOHNS' "Petrolia," New York, **1870** (history); M. L. FULLER, *Ann. Rept. U. S. Geol. Survey*,

	22, iii, 579 (Gaines field); and M. J. MUNN, *U. S. Geol. Survey, Geol. Atlas U. S., Claysville folio* (No. **180**), **1912**.
Philippines	The existence of petroleum seeps on Boudoc peninsula, Tayabas Province, became known soon after American occupation. See *Press Bulletin* No. **17**, Bureau of Science, Government of the Philippine Islands; and RICHMOND, *Philip. J. Sci.*, **5** (1910), 1–7. On the petroleum of Leyte, see PRATT, *Philip. J. Sci.*, **10A** (1915), 241; and on petroleum in the province of Cebu, see PRATT, *idem*, 281. On Philippine oil possibilities, see *Petrol. Rev.*, November 27, **1915**.
Rhode Island	None of the forms of bitumen has been found in Rhode Island.
South Carolina	The occurrence of none of the forms of bitumen has been reported.
South Dakota	Natural gas along with a small amount of oil occasionally occurs in a black shale and sometimes in a light-colored sandstone below, at Ashton, Spink County; at Pierre, Hughes County; and in the eastern part of Sully County. Considerable quantities of natural gas are found at Miller, Hand County, and at Pierre, Hughes County (used locally); but there is no important occurrence of petroleum.
Tennessee	Petroleum occurs in Dickson County (in black Chattanooga shale on Jones Creek); Overton County (Netherland, Spring Creek, and Eagle Creek); Putnam County (near Algood); Scott County (near Glenmary); Fentress and Pickett counties (in Spurrier-Riverton district); also in Clay, Franklin, and other counties. There was no commercial production in Tennessee in 1913, although much interest in the prospects was manifested around Franklin. In 1914, a test was started in Macon County. On petroleum in Tennessee, see G. H. ASHLEY, *Bull. Geol. Survey Tenn.*, No. **2A**, **1910**; J. B. KILLEBREW, *Agric. Rept. Tenn.*, **1877**, pp. 1–116; *Proc. Am. Assn.*, **26** (1878), 266 (geology and topography of region); M. J. MUNN, *Bull. Tenn. Geol. Survey*, No. **2**, **1911** (oil developments); A. H. PURDUE, *Res. of Tenn.*, Jan., **1916** (Central Basin); J. M. SAFFORD, "Geology of Tennessee," Nashville, **1869**; E. J. SCHMITZ, *Eng. Min. J.*, **61** (1896), 228 (oil boom); and A. WINCHELL, *Mining and Manuf. J.*, Jan. 2, **1867**. For a consideration of the question, where may oil be found in Tennessee, see G. H. ASHLEY, *Tenn. State Geol. Survey, Resources of Tenn.*, **2** (1912), No. 7, 262; *ibid.*, 273, M. J. MUNN describes the Spring Creek oil field.

Texas	Petroleum is widely distributed in Texas, the producing counties being: Clay, Duval, Hardin, Harris, Jefferson, Matagorda, McCulloch, McMullen, Navarro, Orange, Shackelford, and Wichita (especially the Electra field). Oil is known to exist in many other counties, but producing wells have not yet been brought in; these counties are Brewster, Brown, Coleman, Gonzales, Reeves, Smith, Walker, Wood. The Coastal Plain oils in the counties of Hardin, Harris, Jefferson, and Matagorda are generally of heavier gravity than the interior oils, such as in Navarro and Wichita counties, although there is also a heavy oil in Navarro County (Powell field). Lubricating oil in small quantities is yielded by some wells in Bexar County, near San Antonio, also in Brown and McCulloch counties. The oil from the later fields (Wichita County) is much lighter than the oil from the Coastal Plain; it probably comes from an entirely different geologic horizon, the Pennsylvanian. The Coastal Plain oils are probably from Tertiary. It is likely that country south, southwest, and west of Wichita County, will be found to be oil-bearing in localized anticlines. The total production of petroleum in Texas amounted to 15,009,478 bbl. in 1913, when 581 oil wells were drilled in northern Texas and 325 in coastal Texas. In 1914, the total production of the State aggregated 20,068,184 bbl. On the oil fields of the western interior and northern Texas coal measures, see G. I. ADAMS, *Bull. U. S. Geol. Survey*, No. **184** (1901). On the oil resources, see G. A. BURR, *Eng. Min. J.*, **71** (1901), 687; C. A. DINSMORE, *Mining World*, **32** (1909), 1118; **33** (1910), 176 (Toyah field); G. D. HARRIS, *Science, N. S.*, **13** (1901), 666; R. T. HILL, *Trans. Am. Inst. Min. Eng.*, **33** (1902), 363 (Beaumont field); A. F. LUCAS, *Compt. rend. Cong. internat. Pétrole*, **2** (1910), 341 (résumé of fields); T. D. MILLER, *Eng. Min. J.*, **65** (1898), 734; *Am. Gas Light J.*, **83** (1905), 86; W. B. PHILLIPS, *Eng. Min. J.*, **93** (1912), 97; and H. V. WALLACE, *Min. Sci. Press*, **103** (1911), 260 (Trans-Pecos region). For a recent report on Texas petroleum fields, see HAZLETT, *Eng. Min. J.*, Jan. 16, **1915**, 137. A "Reconnaissance Report on the Geology of the Oil and Gas Fields of Wichita and Clay counties, Texas," was prepared by J. A. UDDEN and D. M. PHILLIPS for the University of Texas in 1912.
Utah	There were five productive wells in San Juan County, one in Uinta County, and three in Washington County, at the close of 1913. No production was reported, but more or less prospecting was carried on, particularly in Uinta County. Petroleum has been discovered in five other

	counties, namely: Emery, Grand, Wayne, Sanpete and Summit. For the geology of the San Juan oil field, see E. G. Woodruff, *Bull. U. S. Geol. Survey*, No. **471** (1912). On oil near Green River, Grand County, Utah, see C. T. Lupton, *ibid.*, No. **541** (1912). On petroleum in Utah, see G. E. Barbour, *Eng. Min. J.*, **89** (1910), 88; J. M. Boutwell, *Bull. U. S. Geol. Survey*, No. **260**, pp. 468–479 (1905); J. Dern, *Mines and Minerals*, **27** (1907), 250; C. A. Peet, *Salt Lake Min. Rev.*, **11** (1909), No. 18, 19 (on Green River oil fields in Wayne County); G. B. Richardson, *Bull. U. S. Geol. Survey*, No. **340**, pp. 343–347 (1908); A. P. Rogers, *Eng. Min. J.*, **87** (1909), 989; A. V. Taylor, *Salt Lake Min. Rev.*, Jan. 15, **1916**; and W. S. Zehring, *Mining World*, **34** (1911), 596.
Vermont	No forms of bitumen have been reported as occurring in Vermont.
Virginia	Beds of petroliferous character occur at several horizons in the coal fields of Virginia, of Mesozoic and probably Triassic age. These deposits are at present insignificant. See **North Carolina.**
Washington	Petroleum has been found in small quantities in the region of Forks, Clallam County, in which wells have also been drilled near Lapush at the mouth of the Solduck River and near Taholah. It also occurs at Little Chief Mine in the Moses district, Okanogan County; between Tenino and Grand Mound, Thurston County; and at Happy Valley, near Fairhaven, Whatcom County. No production has been reported for the State, but drilling was in progress near the mouth of the Hoh River and also near the mouth of the Queniult River, in 1914. On oil and gas in the western part of the Olympic Peninsula, Wash., see C. T. Lupton, *Bull. U. S. Geol. Survey*, No. **581** (1914).
West Virginia	Petroleum is produced in 26 counties of West Virginia, from Harrison County on the east to the western state line and from Pennsylvania southwest to Mingo County. The production in 1914 amounted to 9,680,033 bbl.; it came principally from Brooke, Cabell, Calhoun, Clay, Doddridge, Gilmer, Hancock, Harrison, Kanawha, Lewis, Lincoln, Marion, Marshall, Monongalia, Ohio, Pleasants, Putnam, Ritchie, Roane, Tyler, Wayne, Wetzel, Wirt, and Wood counties. 1,285 oil wells were drilled in West Virginia during 1913. For an early account of the oil regions of West Virginia, see

	J. H. A. Bone's "Petroleum and Petroleum Wells," New York, **1865**. On its oil fields, see F. W. Brady, *Mines and Minerals*, **28** (1907), 187; **29** (1908), 207; G. P. Grimsley, *Rept. West Va. Geol. Survey*, **1907**; I. C. White, *Am. Geol.*, **7** (1892), 302; *Nat. Gas J.*, **5** (1911), No. 9, 19; and R. V. Hennen, "Doddridge and Harrison counties," *West Va. Geol. Survey*, **1912**.
Wisconsin	Asphalt occurs in small cavities of the Devonian Limestone in Oak Creek township, Milwaukee, and in Fond du Lac. Highly bituminous rock also occurs in layers in the plumbiferous series of like age. No occurrences of petroleum are reported in the literature.
Wyoming	Petroleum is produced in Bighorn County (Byron field); Converse County (Douglas field; heavy black asphaltum oil; local use); Crook County (Belle Fourche field, 20 miles north of Moorcroft; local use for fuel and lubrication); Fremont County (Dallas field); Wind River Reservation; new field begun at Lander (many wells and two kinds of oil); Natrona County (Salt Creek field); Powder River field not producing; Uinta County (Labarge field, along east base of Labarge Range, from Labarge Creek to South Piney; Spring Valley field; numerous small wells from Spring Valley, north, 5 miles); Weston County (several wells near Newcastle got small quantity of oil). Johnson and Lincoln counties are no longer productive. Wyoming produced 1,572,306 bbl. of petroleum in 1912, when it entered as a serious element in the oil industry; 2,406,522 bbl. were produced in 1913; and 3,560,375 bbl. constituted the 1914 production. On the oil fields, see C. E. Jamieson, *Salt Lake Min. Rev.*, Jan. 30, **1916**; A. Lakes, *Mines and Minerals*, **19** (1898), 80; *Mining Sci.*, Apr. 20, **1911**; T. T. Read, *Eng. Min. J.*, **77** (1904), 929; A. R. Schultz, *Bull. U. S. Geol. Survey*, No. **340**, 364–73 (1908). On Wyoming oil springs, see S. Aughey, "Report on Wyoming Oil Springs," Omaha, **1881, 1882**; "Annual Report of Territorial Geologist to the Governor of Wyoming," Washington, **1886**; G. E. Bailey's "Petroleum in Wyoming," **1887**; N. H. Darton, *Bull. U. S. Geol. Survey*, No. **285** (1906) and No. **364** (1908). On the petroleum resources, see R. Douglas, *Petroleum*, **1**, (1901), 1127, 1184; H. E. Havenor, *Salt Lake Min. Rev.*, Jan. 15, **1911** (Byron fields); W. C. Higgins, *ibid.*, Jan. 30, **1911** (Spring Valley field). On the Powder River, Wyo., oil field, see C. H. Wegemann, *Bull. U. S. Geol. Survey*, No. **471** (1912). On the Douglas field, in Converse County, see V. H. Barnet, *idem*, No. **541** (1912), wherein D. F.

	HEWETT describes the Shoshone River section. On the geology of Lincoln County, see A. R. SCHULTZ, *idem*, No. **543** (1914). The Moorcroft field in Crook County is described by BARNET, *idem*, No. **581** (1914). The Douglas oil field in Converse County and the Salt Creek field in Natrona County have been considered by C. E. JAMIESON in special *bulletins* issued by the State Geologist's Office, Cheyenne, Wyo., in 1912; and the fields in Weston, Niobrara, Natrona and Lincoln counties by L. W. TRUMBULL in a report issued by the same office in 1913. On oil near Basin, Wyo., see LUPTON, *Bull. U. S. Geol. Survey*, No. **621-L** (1915).

CHAPTER IV

THE PHYSICAL AND CHEMICAL PROPERTIES OF PETROLEUM

The **composition of petroleum** has been discussed in Chap. I. In this chapter there are considered, first, certain of the physical properties of petroleum, and then the analytical characteristics of various American petroleums.

THE PHYSICAL PROPERTIES OF PETROLEUM[1]

Color.—Crude petroleums are quite variable in character: certain descriptions possess a light color (pale yellow to reddish brown) and may be very mobile, while others are almost black and are viscid. The color of a crude oil is generally taken by reflected light, although, where the oil is translucent, the color

[1] On the physical properties of petroleum, see A. CALMEL, *J. Pétr.*, **9** (1909), 242, 258; **10** (1910), 2, 21, 37, 51; ENGLER, *Chem. Ind.*, **8** (1885), 44; ST. CLAIRE-DEVILLE, *Compt. rend.*, **66** (1868), 442; **68** (1869), 349, 485, 686; **72** (1871), 191; and THOMAS and WATSON, *Proc. Inst. Automob. Eng.*, N.S., **3** (1909), 429. With the exception of the last-mentioned reference, which gives the physical properties of some commercial petrols, the papers noted are of a general nature. For a comprehensive review of the physical characteristics of various crude oils, see GONERE, *Rev. chim. appl.*, **3**, 90.

For a rather full consideration of distillation, the determination of physical constants, and thermochemistry, reference should be had to TINKLER and CHALLENGER'S "The Chemistry of Petroleum and Its Substitutes," London, **1915**, pp. 89, 109, 136, 146, and 292. On relations among the physical constants of petroleum distillates, see RITTMAN and EGLOFF, *J. Ind. Eng. Chem.*, **7**, 578.

On the testing of petroleum, see AISINMANN'S "Taschenbuch für die Mineralöl-Industrie," **1896**; ENGLER and HÖFER'S "Das Erdöl," **1911**; HICKS' "Mineral Oil Testing," **1906**; HOLDE'S "Untersuchung der Mineralöle und Fette," 3d ed., **1909** (English translation, **1915**): LUNGE'S "Technical Methods of Chemical Analysis," Eng. trans., **1914**, **3**, i, 1–57; RAKUZIN'S "Die Untersuchung des Erdöls und seine Produkte," **1906**; and REDWOOD'S "A Treatise on Petroleum," 3d ed., **1913**, **1**, 201; **2**, 198, 200, 220; **3**, 79. These treatises should be referred to for full considerations of methods of procedure and testing apparatus, and also for discussions of the determination of flash-point and solidifying-point and application of the fire test to petroleum products.

by transmitted light is usually recorded also. It is customary in the petroleum industry to judge of the color of petroleum and its products by examination in a 4-oz. sample bottle, approximately 1¼ in. in diameter and 5½ in. in length, and preferably with a plane bottom. For the exact determination of color, use is made either of the chromometer or tintometer.[1]

Color by Transmitted Light.—While most crude oils are opaque, except in very thin layers, when they are brown, many of the thinner grades of Pennsylvania oils and oils lately found in Alberta vary in color from a pale straw to various shades of yellow, red, brown, and deepening shades of brown to black.

Color by Reflected Light.—Crude oils have usually a green cast by reflected light. Otherwise they vary in color from yellow to black—the same as when seen by transmitted light. The greenish color by reflected light is an important characteristic of crude oils, differing from the bluish fluorescence of refined oils. It is frequently a convenient means of distinguishing between crude oils and those which have been manufactured.

Dark crude oils can be deprived of a considerable part of their color by filtration through fullers' earth or clay. This is probably what has occurred in earth where "white" oils are found. "White" crude oils are not common in America, although they sometimes occur. Some "white" crudes have been found in the Los Angeles field, California, which had a specific gravity of 0.810; some in the Placenta Cañon district, California, which had a specific gravity of 0.740; some at Butler, Ohio, with a specific gravity of 0.7407.

Odor.—Petroleums from various regions are so well distinguished by odor that it is often possible to determine the source of a crude oil in this way. Thus, Pennsylvania petroleums possess a peculiar odor, generally described as "gasoline odor;" on the other hand, the crude oils of California, while having much less odor, possess an aromatic smell resembling that of coal-tar oils. The petroleums of Texas and Russia have odors similar to those of the California oils, and an odor resem-

[1] The LOVIBOND tintometer is most in use for the determination of the color of lubricating oils. On this instrument, see LOVIBOND, *J. Soc. Chem. Ind.*, **7** (1888), 424; **9** (1890), 10; and **13** (1894), 308. On the chromometers of WILSON and STAMMER, see REDWOOD'S "Petroleum," 3d ed., **2**, 214; and LUNGE'S "Technical Methods of Chemical Analysis," Eng. trans., **1914**, **3**, part 1, 23 and 60. On the HELLIGE petroleum colorimeter, see UBBELOHDE, *Petroleum*, **10** (1915), 725.

bling that of oil of cedar may be easily detected in the crude oil from the East Indies. Very often these characteristic odors are masked by the disagreeable smell of hydrogen sulphide; then, too, other organic sulphur compounds impart a peculiar disagreeable character to the odors of much of the petroleum from Ontario, which, in this respect, is like the crude oils of Indiana and Ohio.

In order to determine the characteristic odor of petroleum, two samples should be prepared in oil bottles, carefully stoppered and half-filled with the oil. The petroleum is shaken vigorously, so as to impart its odor to the air above the oil in the bottle, and, if this resembles the odor of hydrogen sulphide, 5 c.c. of a fairly strong solution of potassium hydroxide should be added and the oil then shaken until the odor of hydrogen sulphide disappears. In the case of a number of the crude oils from California, agitation with potassium hydroxide solution will give rise to an odor of pyridine. In the second sample, the odor should be noted after similar treatment with 5 c.c. of dilute sulphuric acid.

Specific Gravity.[1]—In general it may be said that all varieties of petroleum are lighter than water, except when contaminated with finely divided mineral matter. Petroleum lighter than 0.780 is rarely found, and the specific gravity ranges commonly between 0.850 and 0.940. Crude oils become denser on exposure to air.

The specific gravity of American petroleums varies from 0.7684 to 0.9960, the reported determinations according to states presenting the following ranges: California, 0.8875–0.9745; Colorado, 0.8092–0.8997; Illinois, 0.8260–0.9236; Indiana, 0.8500–0.9371; Kansas, 0.8350–0.8895; Kentucky, 0.8083–0.9021; Louisiana, 0.8065–0.9669; Michigan, 0.8065–0.8333; New Mexico, 0.8951–0.9186; Ohio, 0.7739–0.8500; Oklahoma, 0.7887–0.8844; Pennsylvania, 0.7901–0.8861; Texas, 0.8065–0.9708; Utah, 0.8202–0.9511; West Virginia, 0.7684–0.8895; and Wyoming, 0.7821–0.9960. A Mexican crude oil having a specific gravity of 1.06 has been mentioned in the literature. The specific gravity of Galician petroleum varies from 0.799 to 0.902;[2] and the petroleum of the Baku district has a density ranging from 0.854 to 0.899.[3]

[1] The determination of the specific gravity of petroleum is described in the second section of this chapter (see pp. 124 and 127).

[2] See NAWRATIL, *Dingler's polyt. J.*, **246** (1882), 423.

[3] It may be mentioned here that a crude oil possessing the low specific gravity of 0.650 has been found at Kudako, Russia.

It has been found that the lighter petroleums usually yield the larger proportion of benzine and kerosene; a high specific gravity, on the other hand, indicates a notable proportion of high-boiling fractions and of asphalt. Mabery and Dunn have shown[1] that Engler's conclusion that the specific gravity of petroleum varies inversely with the depth of the well[2] is not fully supported by their study of the sandstone oils of southern Ohio. The lightest oil was found in the Berea grit, but this stratum also contained the heaviest oil. The petroleum from the 500-ft. sand was almost as light (specific gravity, 0.7971) as that from the 1,500-ft. sand of the Berea grit (0.7939); but the latter was also found to contain the heaviest oil of all the sandstones of southern Ohio (0.8274). Probably certain descriptions of crude petroleum have been subjected to a process of selective filtration through porous strata, whereby they have been deprived of some of their original constituents.[3]

While the specific gravity gives very little indication as to the source of a petroleum, it may serve as a useful guide in the classification of crude oils of known origin. It has, in fact, a considerable commercial importance for purposes of comparison and identification, since the specific gravity constitutes the simplest means of controlling deliveries of petroleum.

The Baumé Scale.—Hydrometers marked with the empirical Baumé scale, instead of the graduation in units and decimals of specific gravity, have been commonly used in the petroleum industry from its very inception. Though the Baumé scale has no marked advantage over the rational scale, the refiner has adhered to its use through custom.

[1] *Am. Chem. J.*, **18**, 224.

[2] American petroleum technologists incline to the view that the specific gravity of oil *decreases* with the depth. Cf. RAKUZIN's conclusions on p. 114.

[3] See DAY, *Proc. Am. Phil. Soc.*, **36**, 112; *Science*, N.S., **17**, 1007; *Cong. internat. pétrole, Paris*, **1900**, 53; DAY and GILPIN, *J. Ind. Eng. Chem.*, **1** (1909), 449; GILPIN and BRANSKY, *Am. Chem. J.*, **44**, 251; and GILPIN and SCHNEEBERGER, *ibid.*, **50**, 59.

On the effect of fullers' earth, unburned kaolin, etc., upon petroleum, see UBBELOHDE and ST. PHILLIPPIDE, *Petroleum*, **7**, 1233; and anon., *Chem. Techn. Ztg.*, **30**, 125. On the physical and chemical action of argillaceous earth on petroleum, see GUISELIN and HAUDRICOURT, *Petrol. Rev.*, **27**, 151; and *Mat. grasses*, **5**, 2815, 2845, and 2882. See also WASHBURNE's paper on capillary concentration in *Bull. Am. Inst. Min. Eng.*, **1914**, 2365.

TABLE VI.—EQUIVALENTS OF THE BAUMÉ SCALE AND SPECIFIC GRAVITY[1]

Baumé	Specific gravity	Lb. per gal.	Baumé	Specific gravity	Lb. per gal.
10	1.0000	8.33	61	0.7329	6.11
11	0.9929	8.27	62	0.7292	6.07
12	0.9859	8.21	63	0.7254	6.04
13	0.9790	8.16	64	0.7217	6.01
14	0.9722	8.10	65	0.7179	5.98
15	0.9655	8.04	66	0.7143	5.95
16	0.9589	7.99	67	0.7107	5.92
17	0.9524	7.93	68	0.7071	5.89
18	0.9459	7.88	69	0.7035	5.86
19	0.9396	7.83	70	0.7000	5.83
20	0.9333	7.78	71	0.6965	5.80
21	0.9272	7.72	72	0.6931	5.78
22	0.9211	7.67	73	0.6897	5.75
23	0.9150	7.62	74	0.6863	5.72
24	0.9091	7.57	75	0.6829	5.69
25	0.9032	7.53	76	0.6796	5.66
26	0.8974	7.48	77	0.6763	5.63
27	0.8917	7.43	78	0.6730	5.60
28	0.8861	7.38	79	0.6698	5.58
29	0.8805	7.34	80	0.6666	5.55
30	0.8750	7.29	81	0.6635	5.52
31	0.8696	7.24	82	0.6604	5.50
32	0.8642	7.20	83	0.6573	5.48
33	0.8589	7.15	84	0.6542	5.45
34	0.8537	7.11	85	0.6511	5.42
35	0.8485	7.07	86	0.6481	5.40
36	0.8433	7.03	87	0.6451	5.38
37	0.8383	6.98	88	0.6422	5.36
38	0.8333	6.94	89	0.6392	5.33
39	0.8285	6.90	90	0.6363	5.30
40	0.8235	6.86	91	0.6335	5.28
41	0.8187	6.82	92	0.6306	5.25
42	0.8139	6.78	93	0.6278	5.23
43	0.8092	6.74	94	0.6250	5.21
44	0.8046	6.70	95	0.6222	5.18
45	0.8000	6.66	96	0.6194	5.16
46	0.7955	6.63	97	0.6167	5.14
47	0.7909	6.59	98	0.6140	5.11
48	0.7865	6.55	99	0.6113	5.09
49	0.7821	6.52	100	0.6087	5.07
50	0.7777	6.48	101	0.6060	5.05
51	0.7735	6.44	102	0.6034	5.03
52	0.7692	6.41	103	0.6008	5.00
53	0.7650	6.37	104	0.5983	4.98
54	0.7609	6.34	105	0.5957	4.96
55	0.7568	6.30	106	0.5932	4.94
56	0.7527	6.27	107	0.5907	4.92
57	0.7487	6.24	108	0.5882	4.90
58	0.7447	6.20	109	0.5858	4.88
59	0.7407	6.17	110	0.5833	4.86
60	0.7368	6.14			

[1] All densities taken at temperatures of 60°F. and referred to distilled water at 60°F. as standard. On equivalents of the Baumé scale, see also N. H. FREEMAN'S "Baumé and Specific Gravity Tables," London, **1914**; and *Circular* **57**, *Bureau of Standards*, **1916**.

Antoine Baumé first published his scale for liquids lighter than water about 1768.[1] He derived his values from solutions of salt and water, and, as his methods were what would now be known as crude, his errors were so large that an exact duplicate of his original solutions is impossible. Since the appearance of this first scale there have been some fourteen different scales by various authorities, each known as the "Baumé" scale. The scale based upon the following formulas is the best and most desirable and has been adopted by the Bureau of Standards:

$$\text{Degrees Baumé} = \frac{140}{\text{specific gravity } \frac{60°}{60°} F.} - 130.$$

$$\text{Specific gravity} = \frac{140}{130 + Bé.° \frac{60°}{60°} F.}$$

Table VI., on page 95, shows the specific gravity of the liquid and the pounds in a gallon for each degree Baumé, in accordance with the foregoing formulas.

Coefficient of Expansion.—While coefficients of expansion do not find a place among the generally accepted characteristic constants of mineral oils, they are required for calculating specific gravities to different temperatures and for determining the expansion space to be allowed in storage vessels and for transport.[2]

The expansibility of petroleum may be determined either by taking the specific gravity at successive temperatures or by a dilatometric method.[3] The coefficient of expansion of Pennsylvania petroleum is 0.000840, and that of Russian oil is 0.000817; it may be said to decrease as the specific gravity rises, the exceptions which occur being attributable to the chemical nature

[1] On the history of hydrometry, see *Chem.-Ztg.*, **39** (1915), 913 and 985.

[2] On the expansion of petroleum and on the determination of the weights and measures of petroleum cargoes, see Davies' "Petroleum Tables," 5th ed., **1912**.

[3] See Holde's "Untersuchung der Mineralöle und Fette," **1909**; Holde's "Examination of Hydrocarbon Oils," **1915**. For a full treatment of the coefficient of expansion of petroleum, more particularly in connection with the deportment of heavy distillates and residues from petroleum, see Holde, *Mitt. k. techn. Versuchsanst.*, **11** (1893), 45.

of the oils. The coefficients of expansion of a number of typical crude oils are given in Table VII., prepared by Engler.[1]

TABLE VII.—COEFFICIENTS OF EXPANSION OF VARIOUS CRUDE OILS

Origin	Pennsylvania	Canada	Schwabweiler (Elsass)	W. Virginia	Schwabweiler (Elsass)	Wallachia	Eastern Galicia	Rangoon	Caucasus	Western Galicia	Ohio	Baku (Benkendorf property)	Oedesse (Hanover)	Pechelbronn Pit Oil	Wallachia	Oberg (Hanover)	Weitse (Hanover)
Coefficient of expansion × 1,000,000..	840	843	843	839	858	808	813	774	817	775	748	784	772	792	748	662	647
Sp. gr. × 1,000.....	816	828	829	841	861	862	870	875	882	885	887	890	892	892	901	944	955

Markovnikov and Ogloblin[2] calculated the coefficient of expansion from the specific gravity of the oil—between 0° and 39.8°C.; the results obtained with a sample of American petroleum were as follows:

Density at 15°C. × 1,000	Coefficient of expansion × 100,000
Under 700	90
700–750	85
750–800	80
800–815	70
Above 815	65

The early results obtained by St. Claire-Deville[3] were limited to temperatures between 0° and 50°C. All researches show that the coefficients of expansion of liquids vary as the temperature rises;[4] therefore the formula for solid bodies—viz., $V = V_0 (1 + at)$—serves only to give an approximate result between agreed temperatures in conjunction with the specific gravity. The results obtained by Gintl, as reported by Höfer,[5] afford confirmation to those of Markovnikov and Ogloblin regarding the relation between the specific gravity and the coefficient of expansion of oils; these are given in Table VIII.

[1] *Verh. Ver. Beförd. Gewerbfl. Preuss.*, **66** (1887), 643.

[2] *J. Russ. Phys.-Chem. Soc.*, **15**, 237.

[3] *Compt. rend.*, **66**, 442; **68**, 349, 485, 686.

[4] LANDOLT and BÖRNSTEIN, "Physikalisch-Chemische Tabellen," 4th ed., 341.

[5] "Das Erdöl," **1888.**

TABLE VIII.—RELATION OF COEFFICIENT OF EXPANSION TO SPECIFIC GRAVITY

Origin	Density × 1,000 at		Coefficient of expansion × 100,000
	0°C.	50°C.	
West Virginia (White Oak)	873	853	46
West Virginia (Burning Spring)	841	808	81
Pennsylvania (Oil Creek)	816	784	82
Canada	870	851	44
Burma (Rangoon)	892	861	72
Russia (Baku)	954	920	71
Eastern Galicia	870	836	81
Western Galicia	855	852	77
Rumania (Ploiesti 1)	862	829	80
Rumania (Ploiesti 2)	901	869	73
Italy (Parma, Neviano de' Rossi)	809	772	96
Hanover (Oberg)	944	914	66
Elsass (Pechelbronn)	912	880	73
France (St. Gabian)	894	861	69
Zante	952	921	67

Bartoli and Stracciati[1] examined the fractions obtained from Pennsylvania crude petroleum, including the saturated hydrocarbons from pentane, C_5H_{12}, to hexadecane, $C_{16}H_{34}$, and obtained the following results:

TABLE IX.—COEFFICIENTS OF EXPANSION OF PETROLEUM FRACTIONS

Hydrocarbon	Boiling point	Specific gravity at 0°	Average coefficient of expansion between 0° and 300°
C_5H_{12}	+30°	0.64025	0.0015890
|	|	|	|
$C_{16}H_{34}$	+278–282°	0.82873	0.0008045

While some preliminary work had been carried out,[2] no thorough investigation had been made of the expansion of mineral lubricating oils until elaborate experiments were conducted by the Charlottenburg Versuchsanstalt. The subject is of practical importance in that it facilitates the estimation of the specific gravity at different temperatures, and the comparison

[1] *Gazz. chim. ital.*, **15** (1886), 417.

[2] ALBRECHT, *Ann. Gewerbe Bauwesen*, **30**, 234; and VEITH, "Das Erdöl und seine Verarbeitung," **1892.**

of the relation between increase of fluidity and increase of volume. The question of fluidity has an important bearing on the value of lubricating oils; and the coefficient of expansion, besides its interest in this particular, also serves to explain other peculiarities observable in mineral oils, particularly the part played by solid hydrocarbons.

Until the Charlottenburg investigation,[1] experiments on expansion had been based upon the formula $V = V^1 (1 + at + bt^2 + ct^3)$, the constants, a, b, and c, having different values at different temperatures, as shown by Kopp and others. Preliminary experiments were made to ascertain the relative advantages of the determination of the coefficient, by weighing a constant volume at different temperatures, and by direct measurement of the increase in volume; the most suitable form and dimensions of dilatometers and pyknometers, and the method of applying heat so as to produce and maintain a constant and equable temperature throughout the oil under test, being also considered. The use of a dilatometer with a bulb holding 30 c.c. and a tube of a diameter of 1.7 to 1.8 mm., was decided on, the thermometer for the experiments being graduated to 1/10°C. This made estimation to the fifth decimal place possible. Table X. shows the effect on the coefficient resulting from error in the dilatometer or pyknometer and thermometer.

TABLE X.—EFFECT OF INSTRUMENTAL ERRORS IN THE DETERMINATION OF THE COEFFICIENT OF EXPANSION

Instrument	Cubical contents	Difference in temperature between observations	Error of instrument	Error of thermometer	Error of coefficient of expansion
	c.c.	°C.	c.c.	°C.	
Dilatometer	10.0	20	0.5	0	0.000025
	25.0	20	0.5	0	0.0000010
	24.0	12	1.0	0	0.0000030
	30.0	10	1.0	0	0.0000030
	30.0	4	1.0	0	0.0000076
	24.0	13	0	0.1	0.0000056
Pyknometer	1.5	15	1 mg.	0	0.0000600
	1.5	30	1 mg.	0	0.0000200

[1] See HOLDE, *op. cit.*

The formula used was:

$$a = \frac{V_1 - V + V_1 [1 + c(t - 20)](t_1 - t)c}{V[1 + c(t - 20)](t_1 - t)},$$

c being the coefficient of expansion of the glass tube, taken as $= 0.000025$, the dilatometer being calibrated at 20°C. This resolves into:

$$a = \frac{V_1 - V}{t_1 - t} \cdot \frac{1}{V[1 + c(t - 20)]} + c \cdot \frac{V_1}{V}.$$

Of which the divisions

$$\frac{1}{[1 + c(t - 20)]} \text{ and } \frac{V_1}{V}$$

may be disregarded in making the calculations, bearing in mind that leaving out $\frac{V_1}{V}$ causes an error of -1 to -2 units in the seventh decimal, and that the omission of $\frac{1}{[1 + c(t - 20)]}$ has the following effect:

When $t - 20 = 10$, the error is $+1$ to 2 units in the seventh decimal.

When $t - 20 = 20$, the error is $+3$ in the seventh decimal.

When $t - 20 = 40$, the error is $+6$ in the seventh decimal.

The formula, thus simplified, becomes:

$$a = \frac{V_1 - V}{(t_1 - t)V} + c.$$

The results given in the tables prepared by Holde[1] show that the variations in the expansive properties of mineral lubricating oils of different origin are but slight. The rule that increase in specific gravity is accompanied by decreased expansion holds good in general. The presence of solid hydrocarbons has the effect of reducing the specific gravity of the oil,[2] the coefficient of expansion being simultaneously raised.

The German oils have a comparatively high rate of expansion at low temperatures, but do not expand more than the Russian oils at a higher temperature (between 30° and 50°C.); whereas the coefficient of expansion of the Scottish oils, and such Ameri-

[1] *Loc. cit.*

[2] Owing, according to ALBRECHT, to their high rate of expansion on solution in liquid hydrocarbons.

can oils as are rich in paraffin, increases with the temperature, and exceeds that of the German and Russian oils. The thick blackish oils of various origins which were examined by Holde and his co-workers gave irregular results in the confirmatory experiments, the discrepancies being accounted for partly by the irregular distribution of the solid particles in suspension, and probably also by differences in consistency, especially in the case of one sample, which appeared to be composed entirely of residues. It does not appear from Holde's results that any simple relation exists between change of fluidity and expansion. The variations of fluidity were, of course, greater in oils containing paraffin (solid at low temperatures) than in paraffin-free oils. In fact, the presence of solid paraffin and asphalt exerts a peculiar influence on the fluidity of the oil,[1] especially when the temperature of the sample is reduced, as these bodies require a long time to separate completely, and the establishment of normal testing-conditions is therefore difficult.

The general characteristics deducible from the experiments of the Charlottenburg Versuchsanstalt may be thus summarized:

The heavy viscous mineral lubricating oils of various origins, of a minimum specific gravity of 0.908, present very little variation in the rate of expansion between 20° and 78°C., the coefficient ranging between 0.00070 and 0.00072.

Those containing paraffin, and solid below 20°C., such as the German oils, have between 12° and 20°C., on the melting of the paraffin, a higher coefficient, viz., 0.00075 to 0.00081.[2]

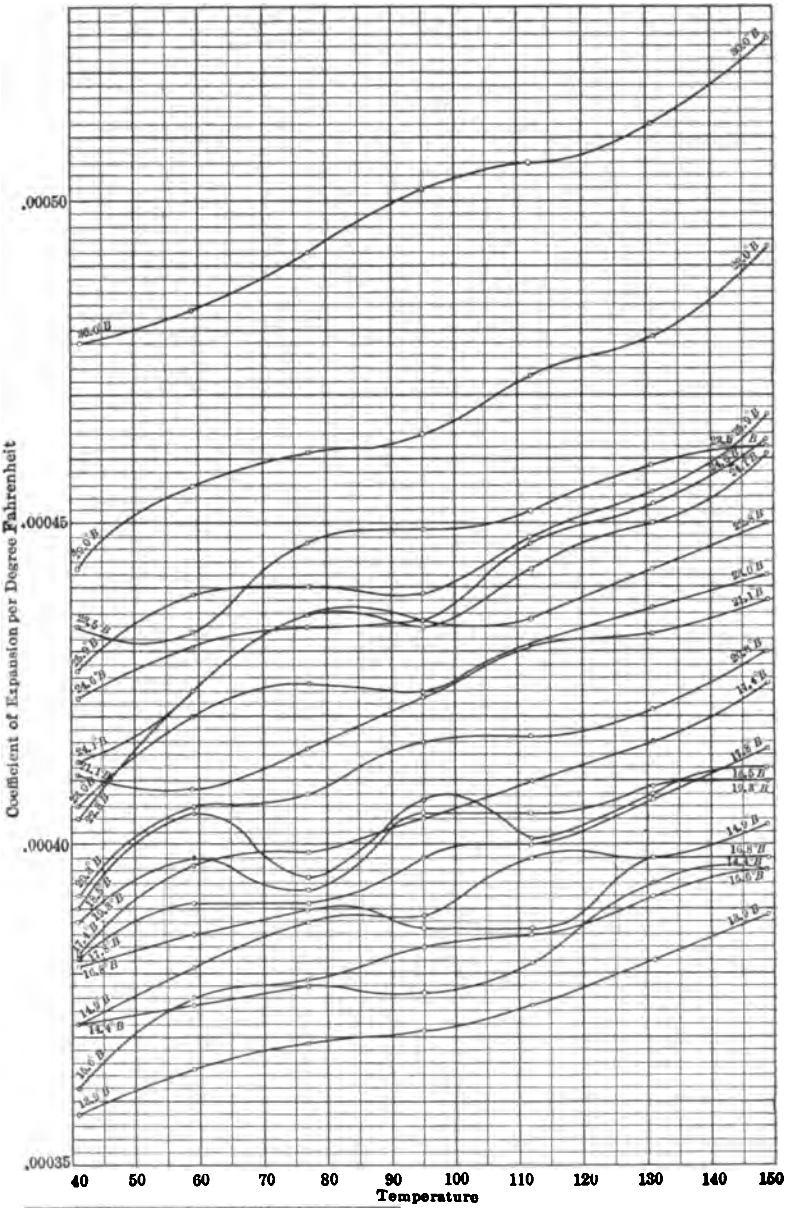
The less viscous oils, for lighter machinery, of specific gravity lower than 0.905 at 15°C., have a higher coefficient than the first class, viz., 0.00072 to 0.00076 between 20° and 78°C.

The completely fluid oils exhibit, with rising temperature, a gradual increase in the rate of expansion. The oils containing paraffin have a decreasing coefficient with increasing temperature until completely fluid, when they follow the above rule.

In the case of kerosene, the practice in the trade in Great Britain is to add or to subtract from the specific gravity at 60°F. 0.0004 for every 1°F. above or below that temperature. According to Redwood's experience, the following corrections for each

[1] On the temperature coefficient of expansion of petroleum residuums, see Rossbacher, *J. Ind. Eng. Chem.*, 7 (1915), 577.

[2] Albrecht found the following differences of the coefficients: 0.0004 for German, 0.0007 for Russian, and 0.0005 for American oils.



30.0°B	Home Oil Co., Coalinga	19.5°B	Well # 4;5-C; Sunset
29.0°B	Well # 35;3-C; Sunset	19.3°B	Well # 15;23-A; Sunset
23.5°B	Well # 7;35-A; Coalinga	17.4°B	Well # 2;1-F; Sunset
25.9°B	Well # 33;5-K; Sunset	17.5°B	Well # 9;23-A; Sunset
24.6°B	Well # 11;5-C; Sunset	16.8°B	Well # 10; Kern River
24.1°B	Well # 10;5-C; Sunset	14.9°B	Well # 2;25-D; Coalinga
21.1°B	Well # 7;23-A; Sunset	14.4°B	Well # 201; Kern River
23.0°B	Well # 1;35-A; Coalinga	15.6°B	Well # 47,25-D; Coalinga
22.5°B	Well # 5;5-C; Sunset	13.6°B	Kern River Storage
20.8°B	Well # 10;11-A; Sunset		

FIG. 13.—Curves showing coefficients of expansion for California oils of various grades at various temperatures.

1°F. should be made: for products lighter than kerosene, 0.00040 to 0.00048; for kerosene, 0.00040; for gas oils, 0.00036; and for lubricating oils, 0.00034.

Tables based upon a formula of Gay-Lussac have been in use in the United States for calculating the alterations in volume of crude petroleum under variations of temperature. At the present time American refiners usually figure temperature allowances as follows: light gasolines—subtract or add 1 per cent. for every 15° above or below 60°F.; all other naphthas and gasolines and illuminating oils—1 per cent. for every 20° from 60°F.; gas and lubricating oils—1 per cent. for every 25° from 60°F.[1]

Boiling Point.—The boiling points of petroleums and the amounts of distillates obtained at specified temperatures therefrom, differ considerably, as will be shown in the next section

TABLE XI.—BOILING POINTS OF CRUDE PETROLEUMS AND AMOUNTS OF DISTILLATES AT VARIOUS TEMPERATURES

Oil from	Specific gravity at 17°C.	Distillation commenced at —°C.	1. Per cent. by volume distilling at °C.										
			Below 130°	130° to 150°	150° to 170°	170° to 190°	190° to 210°	210° to 230°	230° to 250°	250° to 270°	270° to 290°	290° to 300°	Above 300°
Pennsylvania, (1).......	0.8175	82°	15.0	6.0	5.0	5.0	5.0	5.75	4.75	6.0	4.75	2.0	40.75
(2).......	0.8010	74°	24.5	7.0	4.5	4.5	6.5	5.0	4.75	3.25	4.0	2.5	33.5
Galicia (Sloboda Rungurska)..	0.8235	90°	16.0	10.5	10.25	6.5	6.5	7.0	6.75	6.0	3.5	0.5	26.5
Baku (Bibi-Eibat).......	0.8590	91°	16.0	7.0	6.5	6.5	5.0	5.0	5.0	5.5	3.5	1.0	39.0
Baku (Balakhani)........	0.8710	105°	3.75	4.75	5.5	4.75	5.25	5.0	7.0	4.75	5.5	1.75	52.0
Elsass (Pechelbronn).......	0.9075	135°	.....	3.0	4.4	5.4	4.5	6.6	7.3	7.0	10.3	4.5	47.0
Hanover (Oelheim)....	0.8990	170°	.....	.....	.....	4.75	5.25	6.0	4.0	5.0	5.0	2.0	68.0

Product	2. Average percentage yield from oil of				
	Pennsylvania	**Galicia**	**Rumania**	**Elsass**	**Baku**
Light oil.....	10 to 20	3 to 6	4	....	5 to 10.6
Burning oil..	60 to 75	55 to 65	60 to 70	35 to 40	32 to 53.5
Residue......	5 to 10	30 to 40	25 to 35	55 to 60	36 to 60.0

[1] The coefficient of expansion of solar oil is 0.00079.

of this chapter. It is convenient to present here, however, Table XI., the first part of which is by Engler and Levin,[1] and the second by Engler.[2]

Specific Heat.—The specific heats of petroleum and its products are of importance to the refinery engineer. By their use one can calculate the amount of heating surface required in utilizing the heat of steam for preheating oil prior to distillation or in distillation itself and in dehydrating crude petroleum. A knowledge of specific heats is also required in calculating the capacity of a refrigerating plant for the recovery of paraffin wax and in utilizing vapor in heating the oil in a continuous system.

The specific heat of petroleum may be determined by several methods. Gräfe[3] burns 0.41 to 0.43 gram of a substance of known heat of combustion in a bomb calorimeter, in which the sample of oil is used as the outer liquid. From the quantity of substance of known heat of combustion taken (a), the quantity of oil (b), the water equivalent of the calorimeter (W), and the observed rise of temperature (T), the specific heat may be calculated from the formula

$$a.4175 = WT + bcT.$$

A ready method for the determination of the specific heats of petroleum and its distillates consists in bringing into contact, by agitation in a well-insulated glass separatory funnel provided with a thermometer, a sample of the oil and distilled water of the weights M_o and M_w, respectively, and at the respective temperatures of T_o and T_w. The oil-water mixture will come to an intermediate temperature t, such that the number of thermal units given out by the oil is equal to the number gained by the

[1] *Dingler's polyt. J.*, **261**, 32.

[2] *Idem*, **260**, 337. For other similar data, see Krämer, *Sitz. Ver. Beförd. Gewerbfl. Preuss.*, **1885**, 294; and Karmarsch and Heeren, "Technologisches Wörterbuch," 3d ed., **1876**, 618. On the variations of boiling point with altitude, see Lohmann, *Chem.-Ztg.*, **38** (1914), 897.

[3] *Petroleum, Z.*, **2** (1907), 521. For other methods, see Kohlrausch's "Introduction to Physical Measurements" (Eng. trans.), 3d ed., 118; and Reed and Guthe's "Manual of Physical Measurements," 3d ed., 113. The specific heat may also be calculated from the elementary composition: divide the percentages of carbon, hydrogen and oxygen by the respective atomic weights, and multiply these quotients by the atomic heats (C = 1.8; H = 2.3; O = 4.0).

water, or *vice versa*. Then, taking S_o for the specific heat of oil, the equation for the heat exchange is

$$S_o = \frac{M_w(T_w - t)}{M_o(t - T_o)}.$$

In actual practice, it is impossible to avoid loss of heat both by radiation and conduction, but this method is a convenient one for the refinery engineer.

The same method may be used for determining the total heat to be removed from a wax-bearing distillate in cooling it from, say, the vicinity of the cloud-point to the temperature at which the paraffin wax is to be removed from it.[1] This determination can be most conveniently carried out by the reverse operation; that is, by first cooling a sample of the wax-bearing distillate to its final temperature, then ascertaining the total heat required to melt a weighed amount and raising it to the temperature in question, by repeated additions of small portions of water of a sufficiently high temperature, and repeated agitation, until the exact temperature required is arrived at. For example, suppose it is desirable to cool a wax distillate from, say, 80°F. to, say, 20°F. for the purpose of pressing. The sample is cooled down to 20°F., and a weighed portion at that temperature is put in the insulated separatory funnel and water of a sufficient temperature above 80°F., say 100°F., is added in gradual portions, with agitation, until a resulting temperature of 80°F. is indicated by the thermometer. The weight of the water used being known, then from the above-mentioned data can easily be computed the amount of heat used in raising the temperature from 20° to 80°F., which result would be the same as the amount of heat required to be removed to cool from 80° to 20°F. To arrive at the heat to be removed per pound of distillate, letting H_o = total heat per pound to be removed, one should use the formula

$$H_o = \frac{M_w}{M_o}(T_w - t).$$

It will be noted that by obtaining the specific heat of a petroleum product containing in solution a series of solid paraffins of different melting points which crystallize out progressively, the result will be complicated by the heat absorbed in the liquefaction of any member or members of this series or by the heat

[1] For practical purposes, it is not essential that the specific heat and the latent heat of liquefaction be determined separately.

given out in the solidification thereof. Consequently, at temperatures where any paraffin wax crystallizes out, the specific heat shown is true only for that particular range of temperature.

Gräfe found the specific heat of various oils to range from 0.4 to 0.5. It may be noted here that the more hydrogen an oil contains, the higher is its specific heat; and the richer it is in oxygen and carbon, the lower its specific heat.[1]

It has been found by Mabery and Goldstein[2] that impurities lower the specific heats of petroleum hydrocarbons to a considerable extent. These investigators have indicated that although the paraffin series of hydrocarbons affords the best field for study of an homologous series, little has been done in the direction of determining the specific heats of these bodies.

During the course of an investigation of the distillates separated from Pennsylvania petroleum, Bartoli and Stracciati[3] determined the specific heats of certain hydrocarbons to be as follows:

TABLE XII.—SPECIFIC HEATS OF CERTAIN HYDROCARBONS

	Temperature	Specific Heat
Hexane, C_6H_{14}	16°–37°	0.5042
Heptane, C_7H_{16}	16°–37°	0.4869
Octane, C_8H_{18}	12°–19°	0.5111
Decane, $C_{10}H_{22}$	14°–18°	0.5057
Tetradecane, $C_{14}H_{30}$	....	0.4995
Hexadecane, $C_{16}H_{34}$	15°–22°	0.4963

The inference from these results was that the specific heats of these hydrocarbons were remarkably constant.

Mabery and Goldstein[4] gave the following as the results of from three to six determinations of each hydrocarbon, made at the temperatures 0° and 50°:

TABLE XIII.—SPECIFIC HEATS OF CERTAIN HYDROCARBONS

	Boiling point	Specific heat		Boiling point	Specific heat
C_6H_{14}	68°	0.5272	$C_{12}H_{26}$	214°	0.4997
C_7H_{16}	91°	0.5005	$C_{13}H_{28}$	226°	0.4986
C_7H_{16}	98°	0.5074	$C_{14}H_{30}$	242°	0.4973
C_8H_{18}	125°	0.5052	$C_{15}H_{32}$	260°	0.4966
C_9H_{20}	151°	0.5034	$C_{16}H_{34}$	275°	0.4957
$C_{10}H_{22}$	162°	0.4951	Commercial gasoline		0.5135
$C_{10}H_{22}$	172°	0.5021	Crude Ohio petroleum		0.4951
$C_{11}H_{24}$	195°	0.5013			

[1] See the determinations given below and also SCHMITZ, *Mat. grasses*, **6**, 3005.
[2] *Am. Chem. J.*, **28** (1902), 67.
[3] *Gazz. chim. ital.*, **14** (1884), 548; **15**, 417.
[4] *Loc cit.*, 69.

Table XIV. gives the specific heats obtained from the series of methylene hydrocarbons.

TABLE XIV.—SPECIFIC HEATS OF METHYLENE HYDROCARBONS

	Boiling point	Specific heat		Boiling point	Specific heat
C_6H_{12}......	68°	0.5062	$C_{11}H_{22}$......	190°	0.4819
C_7H_{14}......	98°	0.4879	$C_{12}H_{24}$......	212°	0.4570
C_8H_{16}......	119°	0.4863	$C_{13}H_{26}$......	232°	0.4573
C_9H_{18}......	135°	0.4851	$C_{14}H_{28}$......	244°	0.4531
$C_{10}H_{20}$......	160°	0.4692	$C_{15}H_{30}$......	263°	0.4708

It appears from these results that there is a uniform decrease in specific heat with increase in molecular weight. Furthermore, the normal hydrocarbons, such as heptane, C_7H_{16} (b.p., 98°), and decane, $C_{10}H_{22}$ (b.p., 172°), have higher specific heats than their isomers, such, for example, as isoheptane, C_7H_{16} (b.p., 91°), and isodecane, $C_{10}H_{22}$ (b.p., 162°). The same variation also appears in the methylene series, with high values for certain members that probably indicate different structural relations. Mabery and Goldstein call attention to the materially lower values given by the methylene hydrocarbons as compared with the values for the paraffin hydrocarbons; and question whether this is due to greater compactness in the methylene molecule or to some quality of its ring structure.

TABLE XV.—SPECIFIC HEATS OF A SERIES OF HYDROCARBONS SEPARATED FROM THE HIGH-BOILING PORTIONS OF PENNSYLVANIA PETROLEUM AND BELONGING TO THE SERIES C_nH_{2n}[1]

	Boiling point	Specific heat		Boiling point	Specific heat
$C_{16}H_{32}$	173°	0.4723	$C_{23}H_{46}$......	260°	0.4612
$C_{18}H_{36}$......	202°	0.4723	$C_{24}H_{48}$......	272°	0.4586
$C_{20}H_{40}$......	223°	0.4706			

Mabery and Goldstein[2] also determined the specific heat in several hydrocarbons of the series C_nH_{2n-2} and the series C_nH_{2n-4}, which had been separated from Texas petroleum, with the following results:

[1] MABERY and GOLDSTEIN, *loc. cit.*, 71. For the specific heats of the heavier petroleum distillates at high temperatures, consult KARAVAYEV, *Neftjanoje Djelo*, **1913**, No. 16; *Petroleum*, **9**, 550.

[2] *Loc. cit.*, 72.

TABLE XVI.—SPECIFIC HEATS OF SEVERAL HYDROCARBONS SEPARATED FROM TEXAS PETROLEUM

Series C_nH_{2n-2}	Boiling point at 50 mm.	Specific heat	Series C_nH_{2n-4}	Boiling point at 50 mm.	Specific heat
$C_{14}H_{26}$......	127°	0.4447	$C_{21}H_{38}$......	218°	0.4560
$C_{15}H_{28}$......	142°	0.4439	$C_{25}H_{46}$......	273°	0.4650
$C_{16}H_{30}$......	162°	0.4426			

According to Mabery and Goldstein, these findings cannot be accepted as trustworthy, for the quantities of the hydrocarbons were very small and the oils began to crystallize at 0°. There is no doubt that the specific heats of these hydrocarbons are smaller than those of the preceding series.

The same investigators determined the specific heat in the following crude oils from various fields:

TABLE XVII.—SPECIFIC HEAT OF CRUDE OILS, ETC.

	Specific gravity	Specific heat
Pennsylvania	0.8095	0.5000
Berea Grit	0.7939	0.4690
Japanese	0.8622	0.4532
Texas (Lucas well)	0.9200	0.4315
Russian	0.9079	0.4355
Wyoming	0.8816	0.4323
California	0.9600	0.3980[1]
Texas	0.9466	0.4009
Ohio	......	0.4951
Commercial gasoline	......	0.5135

These values show that the specific heat of the crude oils is an important property from a practical point of view. It would also seem that there is no close agreement between specific heat and specific gravity. Pennsylvania oil stands at the head, and Berea Grit, with a much larger proportion of volatile constituents, is next. Of the heavier oils, it appears in general that the specific heats are much lower, but with no definite relation.

It has been found,[2] in the case of California petroleum, that as the asphalt content increases, the specific heat decreases.

Latent Heat of Evaporation.—A knowledge of the latent heat of evaporation of petroleum fractions is necessary to the refinery

[1] More recently WALES (*J. Ind. Eng. Chem.*, **6**, 727) reported that the specific heat of California petroleums varied between 0.3999 and 0.5016, the average on twelve samples being about 0.4500.

[2] By WALES, *ibid.*

engineer for the determination of the requisite heating arrangements, the dimensions of the required condensers, and the supply of condensing water. While, in practice, these data are often arrived at by empirical methods, occasions arise when first principles must be resorted to.

Synievski[1] has devised an apparatus for determining the latent heats as required for the calculation of distilling and condensing plant. Gräfe[2] determines the heat of evaporation by conducting the vapor of the oil through a form of Liebig's condenser and measuring the rate of flow and rise of temperature of the condenser water; he has also shown that the heat of evaporation may be calculated from the molecular weight and the boiling points.[3]

Table XVIII. gives the results which were obtained by Mabery and Goldstein,[4] as the mean of several observations. Mabery and Goldstein have emphasized the practical importance of information concerning the heats of vaporization.[5]

TABLE XVIII.—MEMBERS OF THE SERIES C_nH_{2n+2}

	Boiling point		Heat of vaporization	
	°C.	°F.	Calories	B.t.u.
Hexane, C_6H_{14}	68	154	79.4	143
Heptane, C_7H_{16}	88	190	74.0	133
Octane, C_8H_{18}	125	259	71.1	128

DETERMINATIONS FOR CERTAIN METHYLENE HYDROCARBONS

	Boiling point		Heat in calories	B.t.u.
	°C.	°F.		
Hexamethylene, C_6H_{12}	68–70	154–158	87.3	157
Dimethylpentamethylene, C_7H_{14}	90–92	194–198	81.0	146
Methylhexamethylene C_7H_{14}	98	208	75.7	136
Dimethylhexamethylene, C_8H_{16}	118–119	245	71.7	129

[1] *Z. angew. Chem.*, **11** (1898), 621.

[2] *Petroleum*, **5** (1910), 569.

[3] See also KHARITCHKOV'S "Physikalische Untersuchung des Erdöls."

[4] *Loc. cit.*, 75.

[5] This subject is again referred to in the descriptive account of condensers in the chapter on *Refinery Engineering* (see p. 736).

These results indicate a rapid falling off in latent heat, with increase in molecular weight.

Viscosity.[1]—The determination of the viscosity of mineral oils is generally made in practice by ascertaining the times occupied by two equal volumes of the liquids under comparison to flow through a narrow aperture under exactly the same conditions. The numbers obtained in this way are, of course, entirely arbitrary[2] and differ with the viscosimeters employed for the purpose. For practical purposes, the viscosity of mineral oils has been usually compared with that of rape oil, but the use of the latter is open to the objection that it is difficult to obtain samples of the same viscosity.

The viscosimeters of Saybolt,[3] of Engler,[4] and of Redwood,[5] are the most important of the many forms which have been devised.[6] Saybolt's viscosimeter is in use in the United States,

[1] On the viscosity of mineral oils, see BREUIL, *Bull. conserv. arts metiers*, **1906**, No. 6; CHERCHEFFSKY, *Rev. Chim. Ind.*, **12** (1901), 248; COLEMAN, *J. Soc. Chem. Ind.*, **5** (1886), 359; EDELEANU and DULUGEA, *An. Inst. Geol. Roman.*, **3** (1910), 490; ENGLER, *Chem.-Ztg.*, **9** (1885), 189; HACKEL, *Mitt. k.-k. techn. Gew.*, **15** (1905), 44; HOLDE and STANGE, *Mitt. k. techn. Versuchsanst.*, **18** (1900), 157; KISSLING, *Chem. Rev. Fett-Harz-Ind.*, **9** (1902), 202; MASON, *Chem. News*, **50** (1884), 210; NETTEL, *Chem.-Ztg.*, **29** (1905), 385; OFFERMANN, *Chem. Rev. Fett-Harz-Ind.*, **18** (1911), 272; REDWOOD, *J. Soc. Chem. Ind.*, **5** (1886), 121; SHERMAN, GRAY and HAMMERSCHLAG, *J. Ind. Eng. Chem.*, **1** (1909), 13; SINGER, *Chem. Rev. Fett-Harz-Ind.*, **4** (1897), 243; *Petroleum*, **2** (1907), 555; STEINGRABER, *Petroleum*, **1** (1906), 578; UBBELOHDE, *idem*, **4**, (1909), 861; URE, *Rept. Brit. Assn.*, **1839**, 22; and WHITE, *Petrol. World*, **8** (1911), 499. On the calculation of the degree of viscosity of mineral oil mixtures, see MOLIN, *Chem.-Ztg.*, **38** (1914), 857; and PYHÄLÄ, *Petroleum*, **7**, 207. On the viscosity and rate of flow of hydrocarbon oils, see GLAZEBROOK, HIGGINS and PANNELL, *Engineering*, **100** (1915), 522; *Gas World*, **63** (1915), 515.

[2] On the expression of viscosities in absolute measure, instead of by the arbitrary values now adopted, see especially HIGGINS, *J. Soc. Chem. Ind.*, **32** (1913), 568.

[3] See REDWOOD'S "A Treatise on Petroleum," **2**, 279. On a comparison of the ENGLER and SAYBOLT viscosities of mixed oils, see GRAY, *Orig. Com. 8th Internat. Cong. Appl. Chem.*, **10**, 153.

[4] See ENGLER, *Chem.-Ztg.*, **9** (1885), 189; and *Dingler's polyt. J.*, **286** (1892), 210.

[5] See REDWOOD, *J. Soc. Chem. Ind.*, **5** (1886), 121; HIGGINS, *idem*, **32** (1913), 568; and SAVILL and COX, *idem*, **35** (1916), 151.

[6] On the torsion viscosimeter, see DOOLITTLE, *J. Am. Chem. Soc.*, **15** (1893), 173; on the ENGLER-KÜNKLER instrument, see *Dingler's polyt. J.*, **276** (1890), 42; on the KÜNKLER viscosimeter, see *idem*, **290** (1893), 281; for a description of the LAMANSKY-NOBEL viscosimeter, see WISCHIN, *Chem.*

while the instrument of Engler is used in Germany and generally on the continent in Europe,[1] and that of Redwood is standard in the British Isles.

The relation between Engler and Saybolt viscosimeters, is thus given by S. W. Stratton, Director of the United States Bureau of Standards:[2]

If E_t = time in seconds for outflow of 200 c.c. with Engler,
S_t = time in seconds for outflow of 60 c.c. with Saybolt,

then $E_t = S_tF$

and $S_t = \frac{E_t}{F}$.

where the conversion factors F have the values given in the following table:

E_t Secs.	S_t Secs.	F Conversion Factors
65	37.8	1.72
70	41.7	1.68
80	50.0	1.60
90	58.1	1.55
100	66.2	1.51
125	86.2	1.45
150	106.4	1.41
175	125.9	1.39
200	146.0	1.37
2,400	1,765	1.36

Example 1.—Suppose the observed time of outflow of 60 c.c. with the Saybolt viscosimeter was 1,000 sec. The conversion factor corresponding to S_t = 1,000, taken from the above table, is about 1.365. Hence, the corresponding Engler time is 1,000 × 1.365 = 1,365 sec.

Rev. Fett-Harz-Ind., **7** (1900), 73; and on the PAGLIANI, DETMAR, and GOODMAN apparatus, see FEA, *Proc. Int. Assn. Testing Materials*, **2**, xxi₂.

Instruments for measuring the viscosities of fluids are discussed in principle by MACMICHAEL in *J. Ind. Eng. Chem.*, **7** (1915), 961. MACMICHAEL has devised a viscosimeter which, like the earlier instruments of COUETTE and of CLARK, operates on this general principle: the force required to produce a definite relative movement of the fluid particles in a given time. A disk is suspended in a cup of fluid, and the force exerted by the rotation of the fluid itself is measured. Accuracy, rapidity and convenience are claimed.

[1] In France, however, BARBEY'S "ixomètre" is employed.

[2] See "Petroleum and Natural Gas Resources of Canada," *Bull.* **291**, *Canada Dept. of Mines, Mines Branch*, **1914**, p. 52. On conversion tables for SAYBOLT Universal, ENGLER and REDWOOD viscosimeters, see WAIDNER, *Proc. Am. Soc. Test. Mat.*, **15** (1915), 284; and MCILHINEY, *J. Ind. Eng. Chem.*, **8** (1916), 434.

Example 2.—Suppose the observed time of outflow of 200 c.c. with the Engler viscosimeter was 185 sec. The conversion factor corresponding to E_t = 185, taken from the above table, is about 1.38. Hence the corresponding Saybolt time is

$$\frac{185}{1.38} = 134 \text{ sec.}$$

The above table was found to hold for all the oils tested, ranging from light machinery to heavy cylinder oils, and at all temperatures, 70° to 210°F. The table must not be used below E_t = 65 sec., as none of these viscosimeters is adapted to low viscous oils, as, *e.g.*, illuminating oils.

In the use of the Engler instrument, the so-called Engler numbers are very often used instead of the time in seconds. The Engler number is the time of outflow of 200 c.c. of the oil at the test temperature divided by the time of outflow of 200 c.c. of water at 20°C. With Engler instruments, having the standard dimensions specified for these instruments, and in which the variations do not exceed the specified limits, the time of outflow of 200 c.c. of water at 20°C. is between 50 and 52 sec.

Example.—Suppose the observed Engler time (for 200 c.c. of oil at the test temperature) is 1,000 sec., and that the time of outflow of 200 c.c. of water at 20° has been found to be 51 sec. Then the corresponding Engler number is

$$\frac{100}{51} = 1.96.$$

The above conversion table is given for the time of outflow of 200 c.c. of oil, which is the standard method of using the Engler instrument. When viscous oils are tested at low temperatures, however, the time consumed for the outflow of 200 c.c. is very long. The test can be very much abbreviated by observing the time of outflow of 50 c.c. or of 100 c.c. and multiplying by a suitable factor to reduce to the equivalent time for 200 c.c., in the way explained by Holde in his book on "Untersuchung der Mineralöle und Fette," 2nd ed., 1905.

Although the viscosity of petroleum products of similar chemical characteristics increases with the density,[1] oils of the same specific gravity from different localities often differ in viscosity.

[1] Steingraber, *Petroleum*, 1 (1906), 578.

Table XIX.,[1] showing the relative viscosity of water and various oils, brings out this fact.

TABLE XIX.—VISCOSITY-SECONDS FOR 50 C.C.[2]

Temperature °F.	Water	Refined rape oil	Sperm oil	Neats-foot oil	Beef tallow	American mineral oil			Russian mineral oil		
						Sp. gr. 0.885	Sp. gr. 0.913	Sp. gr. 0.923	Sp. gr. 0.909	Sp. gr. 0.915	Sp. gr. 0.884[3]
50	...	712½	...	620	...	145	425	1,030	2,040	2,520	
60	25½	540	177	470	...	105	295½	680	1,235	1,980	
70	...	405	136⅘	366	...	90	225	485	820	1,320	
80	...	326	113	280	...	73	171	375	580	900	
90	...	260	96	219¼	...	63½	136	262	426	640	
100	...	213½	80½	174¾	...	54	111	200	315	440	1,015
110	...	169	70½	147⅗	...	50	89½	153	226	335	739½
120	...	147	60½	126	...	47	78	126	174	245	531
130	...	123½	57	112	...	44¾	63½	101	135½	185	398½
140	...	105½	50¾	88⅗	...	41	58	82	116	145	317½
150	...	95½	49	75½	...	37½	52	70½	95	115	250
160	...	85	47½	70	...	...	46	63½	83½	93½	200
170	...	76	46	62	...	...	...	58	70½	77½	161
180	...	69	44½	56½	...	...	...	52½	61½	67½	134½
190	...	64½	43	53	...	...	...	47	56½	61	115½
200	...	58½	42	50⅗	54¾	...	...	42	48½	54	99¼
210	...	54	40¾	48½	...	...	...	40	...	...	85
220	...	50	39	47	...	...	...	38	...		77
230	...	47¼	36¾	45⅗	...	...	...	...	...	...	70½
240	...	45½	35¾	44⅗	...	...	...	...	...	...	64½
250	...	43¼	34¾	44	40	...	...	...	...	...	59¼
260	...	...	33¾	43½	...	...	...	...	...	...	54
270	...	...	32¾	43	...	...	...	...	...	...	48½
280	...	...	31 17/20	41½	...	...	...	...	...	...	46½
290	...	...	30¾	41	...	...	...	...	...	...	44¼
300	...	...	30	38	...	...	...	...	...	...	42⅗
310	...	...	...	35							
320	...	...	...	33⅗							

The viscosity of petroleum is of value in determining the facility with which the oil can be pumped with or without heat through pipe lines. It may be noted here that *surface tension* is a constant not yet of value; this is owing to the fact that there is a lack of knowledge regarding the variations caused by the

[1] Determinations of REDWOOD, *op. cit.*

[2] Results with REDWOOD's standard viscosimeter.

[3] Semi-solid at ordinary temperatures. It may be noted here that a lubricating oil which remains fluid at −55°, is described in *Nephtanoje Djelo*, **1912**, 14.

probable presence of small quantities of certain substances in crude petroleums.

Optical Activity.—Certain petroleums and their distillates slightly rotate the plane of polarization; the specific rotatory power of mineral oils is generally 0° to +1.2°, and it rarely rises to +3.1°. The determination is made with the usual polarimetric apparatus.

Zaloziecki and Klarfeld[1] examined a number of Galician oils and one each from Pennsylvania, Russia and Germany. They found that the last three named were inactive, while the light pale descriptions of Galician oils were generally inactive and the dark heavy ones were usually active.

Engler[2] has expressed the opinion that the optical activity of petroleum is, in most cases, caused by the presence of an individual substance, probably the product of a destructive distillation of cholesterin or a cholesterin-like substance; but Koss[3], who made a number of experiments with Ledok and Gogor (Java) petroleum, opposes this view.

Rakuzin[4] concludes that crude oil is dextro-rotatory, the rotatory power being proportional to the depth of the oil-yielding strata, and that the rotatory power of the oil is due to its formation from compounds containing asymmetric carbon atoms. Out of ten Japanese petroleums examined by Rakuzin,[5] only one (Amaze field) was polarimetrically inactive. It had a specific gravity of 0.7877 at 15°C., and was described as a remarkable example of an inactive oil obtained at a great depth (2,100 ft.).

Rakuzin[6] regards the optical activity of petroleum as the most important factor in determining the genesis and geological age of a crude oil. The results of the investigations of 120 petroleums from Caucasia have led Rakuzin to declare that the specific gravity increases with the depth at which an oil is found;

[1] *Chem.-Ztg.* **31** (1907), 1155–1156, 1170–1172.

[2] *Z. angew. Chem.*, **21** (1908), 1585–1597. See also Engler and Bobrzynski, *Petrol. Rev.*, **27**, 41.

[3] *J. Russ. Phys.-Chem. Soc.*, **43** (1911), 697–707. Cf. Engler and Steinkopf, *ibid.*, 1820.

[4] *J. Russ. Phys.-Chem. Soc.*, **41** (1909), 483–500.

[5] *Petroleum*, **6** (1911), 1048. On the relation of the optical activity of petroleum to petrologenesis, see p. 29; and on the significance of optical activity, see Bushong, *Science*, **38**, 39.

[6] *Orig. Com. 8th Internat. Cong. Appl. Chem.*, **25**, 721. See also Rakuzin, *J. Russ. Phys.-Chem. Soc.*, **44**, 1737; *Petroleum*, **7**, 288.

that the carbonization values[1] decrease; that the yields of similar products of distillation are closely associated with depth; and that the paraffin content of crude oil decreases with depth. Zamyatin,[2] however, has indicated that an increase in depth does not always increase the specific gravity of petroleum.[3]

Refractivity.—The refractive index is of technical importance in that it permits of the detection of rosin oil in lubricants. The refractometer of Zeiss is generally employed for this determination.

Refractivity has also petrologenetic significance. For instance, Engler,[4] who has devoted considerable attention to the determination of the power of refracting light possessed by petroleum, is authority for the statement that the most characteristic physical properties indicative of the locality from which an oil is obtained are the *refractive index* and the specific gravity. In support of this statement he has prepared the following table (Table XX.), in which it will be observed that the refractive indices of the oils of Tegernsee and Pechelbronn approach that of Pennsylvania petroleum, while the Oelheim oil affords results not differing greatly from those given by Baku petroleum.

TABLE XX.—REFRACTIVE INDICES OF PETROLEUM DISTILLATES

	Fraction 140°–160°		Fraction 190°–210°		Fraction 240°–260°		Fraction 290°–310°	
	Sp. gr.	Ref. ind.	Sp. gr.	Ref. ind.	Sp. gr.	Ref. ind.	Sp. gr.	Ref. ind.
Tegernsee.....	0.7465	1.427	0.7840	1.437	0.8130	1.451	0.8370	1.465
Pechelbronn (Elsass).....	0.7550	1.421	0.7900	1.440	0.8155	1.454	0.8320	1.462
Oelheim (Hanover)........	0.7830	1.435	0.8155	1.450	0.8420	1.468	0.8620	1.480
Pennsylvania	0.7550	1.422	0.7860	1.439	0.8120	1.454	0.8325	1.463
Baku.........	0.7820	1.436	0.8195	0.454	0.8445	1.467	0.8640	1.475

Moreover, in determining the origin of a petroleum or its products, Chercheffsky[5] notes the refractive index. He presents

[1] The degree of opaqueness determines the carbonization value of a crude oil. This is, according to RAKUZIN, associated with the period of formation of the oil.

[2] *Ann. géol. et min. de la Russie*, **14** (1912).

[3] Cf. p. 94.

[4] *Verh. Ver. Beförd. Gewerbfl. Preuss.*, **1887**, 637.

[5] *Compt. rend.*, **150** (1910), 1338.

the following illustrative results obtained with distillates below 300°C.:

TABLE XXI.—REFRACTIVE INDICES OF PETROLEUM DISTILLATES

Origin	Sp. gr. at 15°C.	Indices of refraction at 15°C.
American	0.780	1.4345
American	0.800	1.4453
American	0.820	1.4564
Russian	0.780	1.4309
Russian	0.800	1.4419
Russian	0.820	1.4533
Rumanian	0.780	1.4334
Rumanian	0.800	1.4458
Rumanian	0.820	1.4572
Galician	0.780	1.4356
Galician	0.800	1.4466
Galician	0.820	1.4586
Shale	0.780	1.4373
Shale	0.800	1.4469
Shale	0.820	1.4568

The following results were obtained with lubricating oils and solid hydrocarbons:

Russian spindle oil, ref. ind. at 15°C.	1.4888
American cylinder oil, ref. ind. at 15°C.	1.4954
Petroleum paraffin, ref. ind. at 15°C.	1.4185
Shale paraffin, ref. ind. at 15°C.	1.4161
Ceresin (ozokerite), ref. ind. at 15°C.[1]	1.426

Using the Zeiss-Abbé refractometer, at the temperature of 15°C., Le Roy[2] obtained these values:

	Refractive index
American crude oil	1.4540
American petroleum spirit (sp. gr., 0.720)	1.3995
American white burning oil	1.4430
Russian crude oil	1.4595
Russian petroleum spirit (sp. gr., 0.720)	1.4105
Russian white burning oil	1.4530
Rumanian crude oil	1.4639
Rumanian petroleum spirit (sp. gr., 0.720)	1.4055
Rumanian white burning oil	1.4560

[1] On the refractometric properties of technical paraffins, see also HOLDE, *Petroleum*, **9**, 669.

[2] *Ann. chim. anal.*, **16** (1911), 12.

According to Kind and Valgis,[1] the refractive index is dependent not upon the boiling point but upon the density. In fact, recent work[2] shows that refractive indices vary in the same direction as specific gravities.

Radioactivity.—Hurmuzescu[3] found that the lightest varieties of certain Rumanian oils examined were the most active and that the activity decreased with time.[4]

Calorific Value.[5]—The examination of fuel oils[6] usually consists in the determination of the calorific value, the specific gravity and the flash-point. The calorimetric value, or calorific power, may be determined in a Berthelot,[7] Kröker,[8] or Mahler[9] bomb, or in a Parr calorimeter.[10] It may be calculated from the elementary composition;[11] but calculations based upon the ultimate analysis of a sample may be quite misleading, since the heat of

[1] *Nephtanoje Djelo,* **12** (1912), 26.

[2] RITTMAN and EGLOFF, *J. Ind. Eng. Chem.*, **7** (1915), 582.

[3] *Petroleum,* **3** (1907), 235.

[4] On the radioactivity of petroleum, see also HIMSTEDT, *Ber. nat. Ges. Freiburg i. Br.*, **14** (1904), 181; HURMUZESCU, *Z. angew. Chem.*, **24** (1911), 26; *Compt. rend. Congress internat. Pétrole*, sess. 3, **2** (1910), 771; and PORUCIC, *Ban. Kohasz. Lap.*, **41,** 163. On a radioactive gas from crude petroleum, see BURTON, *Phil. Mag.*, (6), **8** (1904), 498.

[5] On the determination of calorific values, see ARTH, *Bull. soc. chim.*, (3), **31** (1904), 576. For a consideration of calorific standards and calorimetry, see COSTE's "The Calorific Power of Gas," **1911.** On the accuracy obtainable in fuel calorimetry, see HUNTLY, *Chem. Eng.*, **13** (1911), 147. On the calorimetry of volatile liquid fuels, see RAWLES, *J. Soc. Chem. Ind.*, **26** (1907), 665; and ROSENHAIN, *idem,* **25** (1906), 239.

[6] Crude petroleums, liquid still-residues, "Masut," "Ostatki," tar residues, etc., which are used, where economic considerations permit, for steam-raising purposes. See ZALOZIECKI and LIDOV, *Naphta,* **12** (1904), Nos. 21 and 22; and BOOTH's "Liquid Fuel and Its Apparatus," **1912.** A select index to the literature of fuel oil is given in HOFMAN's "General Metallurgy," **1913,** 288; and good accounts of the present use are given in "Mineral Resources of the United States," **1913,** ii, 950–60; in LEWES' "Oil Fuel," **1913**; in BUTLER's "Oil Fuel," **1914**; and in SCHMITZ's "Die Flüssigen Brennstoffe," **1914.**

[7] *Compt. rend.*, **104,** 875.

[8] *Ber.*, **30** (1897), 605.

[9] *Compt. rend.*, **113,** 774.

[10] See WHITE's "Technical Gas and Fuel Analysis," **1913,** 175.

[11] For formulas used in calculating the heating values of fuels, see GEBHARDT's "Steam Power Plant Engineering," 4th ed., 34; CARPENTER and DIEDERICHS' "Experimental Engineering," 7th ed., 510; and W. A. BONE, THORPE's "Dictionary of Applied Chemistry," revised ed., **1912, 2,** 605.

combustion is dependent upon the state of combination of the elements in the substance and is never equal to the sum of those of its elements taken proportionately.[1]

Table XXII. gives the ultimate analyses of certain petroleums, with their determined calorific powers.

TABLE XXII.—ULTIMATE ANALYSES OF PETROLEUMS

Kind and locality	Bé.	C	H	O + N	S	Calorific power
Heavy oil, Pennsylvania[2]	28	84.9	13.7	1.4	......	10,672
Light oil, Pennsylvania	39	82.0	14.8	3.2	......	9,963
Heavy oil, West Virginia[2]	30	83.5	13.3	3.2	......	10,180
Light oil, West Virginia	36	84.3	14.1	1.6	......	10,223
Heavy oil, Ohio[2]	28	84.2	13.1	2.7	......	10,399
Rothwell, Canada[2]	33	84.3	13.4	2.3	......	11,399
California	.....	86.9	11.8	1.1	......	11,728
California[3]	15	81.5	10.0	6.9	0.55	10,360
Beaumont, Texas[4]	22	84.6	10.9	2.9	1.63	10,578
Heavy oil, Baku[2]	17	86.6	12.3	1.1	......	10,800
Light oil, Baku	28	86.3	13.6	0.1	......	12,650
Refuse, Baku	.....	87.1	11.7	1.2	......	10,700

The investigations begun in 1869 by St. Claire-Deville[5] on the physical properties of crude petroleums from the important oil districts then in operation, showed that the oil of Baku possessed a higher calorific value than that of other districts, and that the practically ascertained heating power was lower than that found by calculation from the known composition of the oil.

Determinations of the calorific values of various descriptions of Texas crude petroleums, made in the laboratory of the University of Texas Mineral Survey,[6] have furnished the following results (Table XXIII.):

[1] See LUCKE's "Engineering Thermodynamics," **1912**, p. 671, for a consideration of calorific power as calculated for oils from ultimate analysis or from density.

[2] POOLE's "Calorific Power of Fuels," **1900**, 251.

[3] PECKHAM "Report on Production, Technology and Uses of Petroleum," 10*th Census U. S.*, **1885**.

[4] MELVILLE, "Report U. S. Naval Fuel Board," **1904**, 68.

[5] *Comp. rend.*, **66**, 442; **68**, 349, 485, 686; **72**, 191.

[6] See PHILLIPS, *Bull. Univ. of Texas*, **1900**, No. 5.

TABLE XXIII.—CALORIFIC VALUES OF TEXAS CRUDE OILS

Source of sample	Calories[1]	B.t.u.[1]
Lucas well, Spindle Top, Jefferson County	10,874	19,574
Higgins Oil and Fuel Co., Spindle Top, Jefferson County	10,992	19,785
Sour Lake, Hardin County	10,201	18,362
Sour Lake, Hardin County	10,305	18,694
Northeast of Fort Stockton, Pecos County	9,655	17,387
Near Dunlay, Medina County	9,372	16,807
Dullnig wells, Bexar County	8,531	15,356
Walsh tract, Bexar County	9,177	16,518

The heating values of various crude petroleums of the oil fields of California are given in the tabular presentment of the analyses of these oils in the next section of this chapter.[2]

Determinations of the calorific values of fuel oils from Burma, Borneo and Texas, of kerosene and solar oil from Russia, and of petroleum spirit from the United States, have given the following results by the bomb calorimeter:

	Gram-calories	B.t.u.
Burma fuel oil	10,794	19,429
Burma fuel oil	10,924	19,663
Borneo fuel oil	10,371	18,668
Borneo fuel oil	10,340	18,612
Texas fuel oil, specific gravity 0.919	10,670	19,206
Texas fuel oil, specific gravity 0.923	10,755	19,359
Texas fuel oil, specific gravity 0.935	10,748	19,346
Texas fuel oil, specific gravity 0.941	10,957	19,722
Russian kerosene	11,260	20,268
Russian solar oil, specific gravity 0.873	10,920	19,656
American petroleum spirit, specific gravity 0.684	12,210	21,978
American petroleum spirit, specific gravity 0.694	12,220	21,996

[1] The gram-calory, or small calory, is the heat required to raise the temperature of 1 gram of water 1°C. From 0° to 1°C. is usually specified, yet it is practically assumed that the specific heat of water is constant; if the calory were defined in terms of the degree from 20° to 21°C., it would more accurately represent the meaning in use. The British thermal unit (B.t.u.) is the pound-degree, or the amount of heat required to raise a pound of water from the temperature 50° to 51°F. (TAIT) or from 62° to 63°F. Gram-calories multiplied by the factor 9/5 (the relation of 1°C. to 1°F.), or 1.8, gives the calorific value in B.t.u. (pound-degrees F.) per pound of combustible. On thermochemical nomenclature, see RICHARDS' "Metallurgical Calculations," 2d ed., pt. 1, p. 13.

[2] See p. 131.

TABLE XXIV.—CALORIFIC POWER OF VARIOUS DESCRIPTIONS OF PETROLEUM, ETC.[1]

Description of oil	Sp. gr. at 0°C.	°Bé.	Chemical composition			Coefficient of expansion	Amount of water evaporated per unit of fuel	Calorific power	
			Carbon	Hydrogen	Oxygen			Calories[2]	B.t.u.
Heavy petroleum from West Virginia	0.873	30.0	83.5	13.3	3.2	0.00072	14.58	10,180	18,324
Light petroleum from West Virginia	0.8412	37.5	84.3	14.1	1.6	0.000839	14.55	10,223	18,401
Light petroleum from Pennsylvania	0.816	41.5	82.0	14.8	3.2	0.00084	14.05	9,963	17,933
Heavy petroleum from Pennsylvania	0.886	28.0	84.9	13.7	1.4	0.000721	15.30	10,672	19,210
American petroleum	0.820	40.5	83.4	14.7	1.9	0.000868	14.14	9,771	17,588
Petroleum from									
Parma	0.786	48.0	84.0	13.4	1.8	0.000706	13.96	10,121	18,218
Pechelbronn	0.912	23.5	86.9	11.8	1.3	0.000767	14.30	9,708	17,474
Pechelbronn	0.892	27.0	85.7	12.0	2.3	0.000793	14.48	10,020	18,036
Schwabweiler	0.861	32.5	86.2	13.3	0.5	0.000858	15.36	10,458	18,824
Schwabweiler	0.829	39.0	79.5	13.6	6.9	0.000843	....	......	......
Hanover, Eddesse	0.892	27.0	80.4	12.7	6.9	0.000772	....	......	......
Hanover, Wietse	0.955	16.5	86.2	11.4	2.4	0.000641	....	......	......
East Galicia	0.870	31.0	82.2	12.1	5.7	0.000813	14.23	10,005	18,009
West Galicia	0.885	28.0	85.3	12.6	2.1 (N,O.)	0.000775	14.79	10,231	18,416
Shale-oil from Ardèche, Vagnas	0.911	23.5	80.3	11.5	8.2 (O,S,N.)	0.000896	12.24	9,046	16,283
Coal-tar from Paris gas-works	1.044	.....	82.0	7.6	10.4	0.000743	12.77	8,916	16,049
Petroleum from Balakhani	0.822	40.75	87.4	12.5	0.1	0.000817	....	11,700	21,060
Light petroleum from Baku	0.884	28.5	86.3	13.6	0.1	0.000724	16.40	11,460	20,628
Heavy petroleum from Baku	0.938	19.0	86.6	12.3	1.1	0.000681	15.55	10,800	19,440
Petroleum-residues from the Baku factories	0.928	21.0	87.1	11.7	1.2	0.00091	....	10,700	19,260
Petroleum from Java	0.923	21.5	87.1	12.0	0.9	0.000769	15.02	10,831	19,496
Heavy oil of pine (Landes)	0.985	12.0	87.7	10.4	2.5	0.000685	14.75	10,081	18,146
Description of fuel	**Solid fuels**								
Coal	.....	.....	....	....	....	....	....	7,500	13,500
Coke	.....	.....	....	....	....	....	....	6,500	11,700
Peat	.....	.....	....	....	....	....	....	4,500	8,100
Turf (air-dried)	.....	.....	....	....	....	....	....	3,800	5,400
Wood	.....	.....	....	....	....	....	....	2,800	5,040

[1] Based upon the table of determinations given in VEITH's "Das Erdöl und seine Verarbeitung," 1892. For other data see POOLE's "Calorific Power of Fuels," 1900, pp. 251 and 252; and HOFMAN's "General Metallurgy," 1913, p. 286.

[2] It will be observed that the calorific power of petroleum is usually about 10,000 calories.

Inchley[1] has given the data presented in Table XXV.

TABLE XXV.—COMPOSITION AND CALORIFIC POWER OF SOME PETROLEUM OILS

Name	Specific gravity	Composition			Calorific power		
		Carbon	Hydrogen	Oxygen, nitrogen, etc.	Kilogram calories per kilogram	B.t.u. per pound	B.t.u. per gallon
"Royal Daylight" (American)	0.797	85.70	14.20	....	11,167	20,100	159,000
Kerosene (American)	0.780	85.05	14.40	0.55	11,163	20,095	156,500
Refined (Baku)	0.825	86.00	14.00	....	11,270	20,300	167,000
Russole, R.U.O.	0.890	85.95	13.50	0.45	10,901	19,620	174,500
Solar oil	0.896	86.61	12.60	0.79	10,783	19,450	174,000

The following formula has been found by Sherman and Kropff[2] to express approximately the relation between the specific gravity and the calorific power (in British thermal units per pound) of American petroleum oils:

$$\text{B.t.u.} = 18{,}650 + 40\ (\text{Baumé degrees} - 10).$$

The relation between calorific power and specific gravity for similar oils is also indicated below, the calorific powers being expressed in calories per gram.

Specific gravity	Calorific power
0.70–0.75	11,700–11,350 calories.
0.75–0.80	11,350–11,100 calories.
0.80–0.85	11,100–10,875 calories.
0.85–0.90	10,875–10,678 calories.
0.90–0.95	10,675–10,500 calories.

Brame[3] has reported the calorific values and specific heats given in Table XXVI.

TABLE XXVI.—CALORIFIC VALUES AND SPECIFIC HEATS OF CERTAIN PETROLEUM OILS

Name	Specific gravity	Kilogram calories per kilogram	B.t.u. per pound	B.t.u. per gallon	Specific heat
"Royal Daylight" ("Tea Rose")	0.8055	11,100	19,980	160,500	0.450
"Water White" ("White Rose")	0.800	11,140	20,050	160,400	0.457
Russian	0.8248	11,060	19,910	164,000	0.435
Rumanian	0.8127	10,900	19,620	159,500	0.444

[1] *Engineer*, **111** (1911), 155.
[2] *J. Am. Chem. Soc.*, **30** (1908), 1626.
[3] "Fuel," p. 170.

Constam and Schlapfer[1] have made a very complete investigation of the chemical and physical properties of 109 samples of petroleum of Galician, Alsatian, and North and South American origin. Their report should be consulted by those interested in oil for power purposes.

THE ANALYTICAL CHARACTERISTICS OF AMERICAN PETROLEUMS

The following tables (XXVII. and XXIX.), with the exception of the analyses of the crude petroleums of the oil fields of California (Table XXVIII.), are based upon the extensive compilation given in *Mineral Resources of the United States*, **1913**, ii, 1121. Commenting upon this presentment, David T. Day states that,

"The degrees of accuracy and the methods of expressing the results differ greatly in the analyses gathered from the general literature of the subject. In arranging the analyses, effort has been made to show the variation in specific gravity, in percentage of sulphur, of asphalt, and of paraffin, and in distillation products. Other analytical data are given under 'Remarks.'

"On the whole, the tables are very incomplete and show clearly the necessity for much additional work. The analyses cited show very full work in some fields and almost nothing in others. In Pennsylvania, New York, Ohio, Indiana, and the newer fields information is lacking as to even the exact locality from which many of the samples came and the conditions under which any particular specimen was obtained. Usually there is no statement as to care used in avoiding evaporation from the sample. Up to 1897 the analytical methods of the older analysts varied to such an extent that as much as 30 per cent. difference in the proportion of naphtha will be shown in two samples from the same region, and thus a far greater difference will be shown between two samples from the same pool, as analyzed by the older analysts, than between the oils from widely separated districts. Yet there are no explanatory statements to make these differences intelligible. No more conclusive argument could be offered for the need of a general review of the analytical characteristics of all American oils."

This need was recognized by sending Day to the Third International Petroleum Congress, held at Bucharest, Rumania, in 1907, where he aided in organizing for the first time an international commission for establishing uniform methods of examining crude petroleum and its products. The international

[1] *J. Gas Ltg.*, **124**, 596.

commission considered, during the week in which the congress was held, the various methods used by different authorities and formulated and recommended to the congress for international adoption a provisional system of analysis. This system was adopted by the congress and it was recommended to the various nations for general adoption, pending any modifications which might be made by an international commission which the congress created for this purpose. This action was reported to the Congress of the United States, in response to a resolution of the Senate, and the rules for analysis were printed as a Senate document.[1] Since 1907 this international commission has held two general seessions, one in London in 1909 and one in Vienna in 1910. At each of these meetings the system adopted at Bucharest was confirmed, with slight additional rules designed to increase accuracy, the fundamental system remaining fixed.

With this uniform system as its basis, the United States Geological Survey, in cooperation with various state geologists, immediately began the collection of samples under uniform conditions from the various fields of the United States. These were then examined by exactly the same methods in order that they might be entirely comparable. The work was limited to crude oils, so that these various natural oils might be classified and be made to show their relations to the rocks in which they occur. The study of the composition of the products manufactured from them, as well as the processes by which they are refined, has been undertaken by the Bureau of Mines. A collection, complete at that time, was made of the oils of the Mid-Continent field, including Kansas, Oklahoma, Caddo, and north Texas. The samples were collected at the wells by members of the Survey. Average specimens were also collected in each field from pipe-line tanks, because this showed the actual average, in which the largest wells were given fairer weight than by an arithmetical average of large and small wells. Efforts were made, in collecting these samples from pipe lines, to select those in which the oil had had chance to be well mixed. The samples were, therefore, as representative as possible. The samples from Illinois and other states were similarly collected by members of the Federal or State surveys.

[1] No. 469, 60th Cong., 1st sess., 1908.

METHOD OF ANALYSIS

Gravity.—A set of very delicate specific gravity spindles was made especially for the investigation of the United States Geological Survey by C. Tagliabue & Sons. The samples are brought to a temperature of 15°C., in a cylinder cooled in a water bath. The specific gravity is then taken.

Distillation.[1]—The samples are then distilled by Engler's method as modified by Ubbelohde and adopted by the international commission. Thus 100 c.c. of the crude oil, measured at 15°C., are delivered by a pipette into a distilling bulb holding about 125 c.c. The dimensions of this bulb are those prescribed by Engler. The thermometer used is a nitrogen thermometer, reading to 550°C., which has been carefully standardized by the United States Bureau of Standards. The condenser tube, as prescribed by Engler, is 75 cm. long and has an inclination of 75° from the horizontal. The point of initial boiling is taken when the first drop of oil falls from the condenser tube into the receiving flask. To avoid loss by evaporation, the condenser tube is ground to fit into the graduated receiving flask, which is provided with a stop cock to draw off the oil at 150°C. and again at 300°C. Note is also taken of the proportions boiling within each range of 25°C., but these details are not published in the tables given herewith. The fraction between the initial boiling point and 150°C. (302°F.), constituting the gasoline fraction, and the fraction between 150° and 300°C. (302° and 572°F.), constituting the kerosene fraction, are examined as to specific gravity with a pyknometer. The residuum is weighed as soon as cool; then its specific gravity is taken in the usual way and the volume calculated. As will be noted, the total thus obtained for the different fractions includes the sum of all variations in the determinations. This total for many samples slightly exceeds 100 per cent., due to errors in coefficient of expansion, etc.; but for a greater number is considerably below that amount, owing to the presence of water, loss of volatile gasoline, etc.

Unsaturated Hydrocarbons.—The method of Krämer and Böttcher is used for determining the unsaturated hydrocarbons

[1] On the fractional distillation of petroleum, see SANDERS, *J. Chem. Soc.*, **105** (1914), 1697. On the analytical distillation of petroleum, see especially RITTMAN and DEAN, *J. Ind. Eng. Chem.*, **7** (1915), 754.

present in the crude oil and in the distillate between 150°C. and 300°C. The quantity of gasoline in many samples was too small for systematic determination of the percentage of unsaturated hydrocarbons in it. The method consists in shaking 25 c.c. of the crude petroleum with 25 c.c. of sulphuric acid of specific gravity 1.83, corresponding to ordinary strong sulphuric acid, about the equivalent of that used in petroleum refining. The acid and oil are shaken in a small flask with a long neck, the neck holding 25 c.c. The flask is then filled with strong sulphuric acid until the oil which remains uncombined with the acid can be measured in the neck of the flask. The loss in volume

TABLE XXVII.—ANALYSES OF PETROLEUM FROM ALASKA, DISTILLATION BY ENGLER'S METHOD

Location of well	Specific gravity at 15°C.	Begins to distil at (°C.)	By volume: To 150°C. Cubic centimeters	By volume: To 150°C. Specific gravity	By volume: 150°–300°C. Cubic centimeters	By volume: 150°–300°C. Specific gravity	By volume: Residuum Cubic centimeters	By volume: Total Cubic centimeters	Sulphur (per cent.)	Remarks
Katalla Bay[1]	0.8280	....	21.0	0.7573	51.0	0.8204	28.0	100.0	.....	Residuum, paraffin-base.
Katalla[2]....	0.7958	....	38.5	......	31.0	......	30.5	100.0	Tr.	Residuum, all over 285°C.; cold test—did not chill at 3°F.
Katalla.....	0.8000	....	34.2	......	34.4	......	31.0	99.6	.....	
Cold Bay[3]..	0.9547	225	....	......	13.3	0.8772	86.7	100.0	0.116	86.7 per cent. residuum includes 8.1 per cent. coke and loss and products distilled under 120 mm. pressure up to 350°C., and also products by destructive distillation.
Oil Bay[3]....	0.9557	230	....	......	13.2	0.8777	86.8	100.0	0.098	86.8 per cent. residuum includes 5.6 per cent. coke and loss and products distilled under 120 mm. pressure up to 350°C., and also products by destructive distillation.

[1] PENNIMAN and BROWNE, *Bull. U. S. Geol. Survey*, No. **225**, 1904.

[2] *Mineral Resources of the United States*, **1902**, 583.

[3] PENNIMAN and BROWNE, *Bull. U. S. Geol. Survey*, No. **250**, 1905.

between the original 25 c.c. and the oil which remains undissolved by sulphuric acid is taken to represent the unsaturated hydrocarbons.

Paraffin Wax.—This was determined by the Engler-Holde method. Two parts of absolute alcohol and one part of absolute ether are used as the solvent, from which the paraffin wax is precipitated on cooling to −20°C.

Asphalt.—The asphalt was determined by Holde's method, by weighing off 1 gram of residuum and shaking this with 40 c.c. of gasoline which was free from unsaturated hydrocarbons and which boiled between 65° and 95°C. After shaking, this was allowed to stand for 48 hours and the precipitated asphalt was dissolved in benzol, dried at 105°, and weighed. Accuracy greater than 1 per cent. was not claimed for these analyses.

Sulphur.—The sulphur is sometimes determined by Burton's method of burning in a lamp, collecting the SO_2 and H_2SO_4 in a solution of sodium carbonate, and titrating with methyl orange; and sometimes by the bomb. When both methods are used on the same sample the results are consistent.

THE CRUDE PETROLEUMS OF THE OIL FIELDS OF CALIFORNIA

About 600 analyses of samples of crude petroleum from various districts in the oil fields of California, have been reported to date in the literature.[1] However, the most comprehensive investigation of the physical and chemical properties of the petroleums of the state was that recently conducted by the Federal Bureau of Mines, and accordingly the results of the work of Allen, Jacobs, Crossfield and Matthews[2] are presented in some detail below.

The methods of collecting samples and making analyses employed by Allen and his co-workers, merit brief description.

[1] For a compilation of these analyses up to 1914, see *Mineral Resources of the United States*, **1913**, ii, 1127–1177.

[2] *Technical Paper* **74**, *Bureau of Mines*, **1914**. For additional data, see Ralph Arnold and Robert Anderson, "Geology and Oil Resources of the Coalinga District, California, with a Report on the Chemical and Physical Properties of the Oils by I. C. Allen," *Bull. U. S. Geol. Survey*, No. **398** (1910), 264–272; also I. C. Allen and W. A. Jacobs, "Physical and Chemical Properties of the Petroleums of the San Joaquin Valley of California," *Bull.* **19**, *Bureau of Mines*, **1912**.

Sampling.[1]—The samples, collected at the wells, were put in 1-gal. tin cans that were soldered tight and shipped at once to the laboratories where the analyses were made. The samples were taken, where possible, by allowing the oil to run from the outflow of the well directly into the sample can; where this method was impracticable, a dipper was used. After the can was filled it was soldered tight as soon as possible. Oil that had been exposed to atmospheric influences for even a short period was not collected.

Specific Gravity.—The specific gravity was determined by means of the Westphal balance.

Flash-Point.—As most of the crude oils examined contained at least a trace of water, they showed a marked tendency to froth when heated and gave considerable difficulty with the closed Pensky-Martens[2] flash tester, many frothing over at temperatures much below the flash-point of the oil. For this reason, and to obtain comparative tests, it was considered advisable to determine the flash-point of all the crude samples in an open Pensky-Martens cup, carefully screened from air currents. On account of the frothing of the samples, the temperature had to be increased slowly; a rise of 2° to 3°C. per minute was found to give good results. The gas test flame, of the size and form recommended for the Abel tester,[3] was exposed for one second 1 cm. above the surface of the oil, at each rise of 1°C., beginning at 10° below the flash-point, as determined by a preliminary test.[4]

Burning Point.—After the flash had been determined, the heating was conducted without interruption, exactly as before, until the "flash" became permanent, that is, until the oil ignited and continued to burn quietly.

Viscosity.—The viscosity was determined in an Engler viscosimeter[5] at 20°C.

[1] For detailed methods of sampling, see I. C. Allen, "Specifications for the Purchase of Fuel Oil for the Government, with Directions for Sampling Oil and Natural Gas," *Tech. Paper* **3**, *Bureau of Mines*, **1911.**

[2] Benedikt-Ulzer, "Analyse der Fette und Wachsarten," **1908**, pp. 386–388. Boverton Redwood, "Petroleum and Its Products," **1906**, **2**, pp. 593–594. Holde, "Untersuchung der Mineralöle und Fette," **1909**, p. 133.

[3] Boverton Redwood, "Petroleum and Its Products," **1906**, **2**, pp. 566–567.

[4] I. C. Allen and A. S. Crossfield, "The Flash-point of Oils, Methods and Apparatus for Its Determination," *Tech. Paper* **49**, *Bureau of Mines*, 1913, pp. 17–21.

[5] Benedikt-Ulzer, "Analyse der Fette und Wachsarten," **1908**, pp. 58–61. Boverton Redwood, *op. cit.*, pp. 602–603.

Calorific Value.—The calorific value was determined in a Berthelot combustion bomb[1] (Dinsmore-Atwater model). The British thermal units per pound were calculated by multiplying the calories per gram by 1.8.

Sulphur.[2]—Sulphur was determined by carefully washing out with distilled water the contents of the bomb after the combustion, the sulphuric acid being precipitated with barium chloride in the usual manner, and the percentage of sulphur calculated.[3]

Water.[4]—Water was determined during the course of an ordinary fractionation; it distilled over in those fractions having a boiling point between 100° and 150°C. under atmospheric pressure, and could be removed readily from the receivers with a micropipette and weighed. Usually a few drops of water adhered to the condenser and failed to run into the receivers; in this event, a small pellet of absorbent cotton moistened with water, squeezed as dry as possible and weighed, was fastened to a wire and run up into the condenser to remove these last traces of water. The weight of the drops was determined by the increase in weight of the cotton pellet.

Fractionation.—The fractionation was made in an electrically heated still,[5] and was conducted as follows:

[1] "Report on the Operations of the Coal Testing Plant of the United States Geological Survey at the Louisiana Purchase Exposition, St. Louis, Mo., **1904**;" *U. S. Geol. Survey, Prof. Paper* **48,** 1905, p. 179; and J. A. Bownocker, N. W. Lord, and E. E. Somermeier, "Coal," *Bull. Geol. Survey of Ohio,* No. **9,** 4th ser., 1908, pp. 420–424.

[2] For detailed methods for the determination of sulphur, see I. C. Allen and I. W. Robertson, "Methods of Determining the Sulphur Content of Fuels, especially Petroleum Products," *Tech. Paper* **26,** *Bureau of Mines,* **1912.**

[3] I. C. Allen, "Relative Values of Fuels used on the Pacific Coast," *Min. Sci. Press,* Dec. 8, **1900,** p. 569. R. Arnold, R. Anderson, and I. C. Allen, "Geology and Oil Resources of the Coalinga Oil District, California," *Bull. U. S. Geol. Survey,* No. **398,** 1910, p. 265.

[4] For detailed methods for the determination of water, see I. C. Allen and W. A. Jacobs, "Methods for the Determination of Water in Petroleum and Its Products," *Tech. Paper* **25,** *Bureau of Mines,* **1912.** On the use of calcium carbide in estimating water in petroleum and its products, see Roberts and Fraser, *J. Soc. Chem. Ind.,* **29** (1910), 197; and Allen and Jacobs, *Orig. Com. 8th Inter. Congr. Appl. Chem.,* **10** (1912), 17.

[5] For detailed description of the still and method of distillation, see I. C. Allen and W. A. Jacobs, "Physical and Chemical Properties of the Petroleums of the San Joaquin Valley of California," *Bull.* **19,** *Bureau of Mines,* **1911,** pp. 29–33.

Two hundred grams of the sample of oil were weighed into a ¼-liter flask of the dimensions shown in Fig. 14. The flask was then connected to a Liebig condenser placed vertically, and the distillates were collected in weighed receiving tubes placed in a Bruehl receiver. The oil was distilled under atmospheric pressure at increasing temperatures up to 325°C., the receivers being changed at each increment of 25°. The temperature was then allowed to drop to 125°C., to keep the oil from boiling over when the vacuum was used, and the distillation was again continued under a vacuum of 10 to 20 mm. mercury pressure till the temperature within the flask reached 325°C.

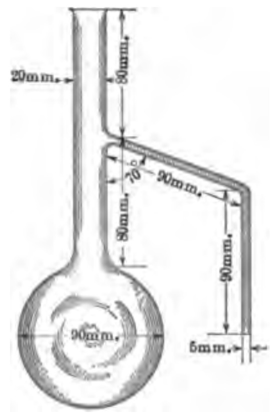


FIG. 14.—Flask for distilling petroleum.

Refining.[1]—The oils—naphthas, lamp oils, and lubricants—were further refined as follows: 250 grams of the oil were put in a 1-liter separatory funnel and shaken vigorously; that is, 120 to 150 shakes per minute for 15 min. in a shaking machine, as follows: four times with 10 c.c. of concentrated sulphuric acid (or until the oil was not appreciably colored by this acid treatment), once with a 10 per cent. solution of sodium carbonate to remove the free acids, and three or four times with water to remove the last traces of soda, etc. The oil was then dried with Glauber salt and distilled. This refining acid treatment yielded a water-white, practically odorless product of excellent quality.

Because of their high viscosity, the heavier fractions (those distilled under a vacuum at temperatures above 250°C.) were diluted with one part of chemically pure benzene before subjecting them to the acid treatment.

Naphtha Distillates (Unrefined Naphthas).—Those fractions that boil at temperatures up to 150°C., under atmospheric pressure, comprise the "unrefined naphthas."

Kerosene Distillates (Unrefined Lamp Oils).—Those fractions boiling between 150° and 300°C., under atmospheric pressure, comprise the "unrefined lamp oils."

Unrefined Lubricants.—Those fractions boiling between 300°C.,

[1] On the separation and determination of paraffin, see *Technical Paper* **74**, *Bureau of Mines*, **1914**.

under atmospheric pressure, and 325°C., under a vacuum of 10 to 20 mm. mercury pressure, comprise the "unrefined lubricants."

Asphaltum Residue.—That part remaining in the flask, undistilled, is termed "asphaltum residue." In practically all of the oils examined this residue was a jet-black, lustrous mass, that was brittle at room temperatures and had a consistency much like ordinary taffy. It could be chewed, but was very sticky when slightly warmed; on solution in benzene it left no appreciable quantity of carbon flecks. This showed that these asphaltum petroleums, after removal of the oils distillable at temperatures up to 325°C., under a pressure of 10 to 20 mm. of mercury, leave a residue of solid elastic asphaltum usable for commercial purposes.

Refining Losses.—The above acid treatment causes a total loss of approximately 11 per cent. in the oil treated. This loss is too high and should be reduced.

TABLE XXVIII.—RESULTS OF EXAMINATION OF CALIFORNIA PETROLEUMS[1]

District	Specific gravity at 15°C.	Degrees Baumé at 60°F.	Heating value Per gram	Heating value Per pound	Heating value Per gallon	Wt. per gallon, lb.	Flash point (open cup), °C.	Burning point (open cup), °C.	Viscosity at 20°C. (Engler scale)	Water, per cent.	Sulphur, per cent.	Naphtha (unrefined), per cent.	Fuel oil, per cent.	Gasoline (refined), per cent.	Lamp oil (refined), per cent.	Lubricants (refined), per cent.	Refining losses, per cent.	Distilling losses, per cent.	Asphaltum (commercial), per cent.
Los Angeles City	0.9629	15.40	10,246	18,443	147,931	8.0227	107.0	145.0	272.5	1.7	0.62	0.0	98.3	0.0	4.5	32.1	12.5	0.6	48.6
La Brea, Salt Lake or Santa Fe	0.9604	15.61	10,117	18,210	146,087	8.0018	46.0	89.0	574.3	0.9	2.29	0.0	99.1	0.0	13.0	22.3	9.6	0.9	53.3
Fullerton	0.9207	22.26	10,439	18,790	144,060	7.6711	17.9	52.1	110.5	0.2	0.89	0.3	99.5	0.3	21.7	24.1	10.3	1.3	42.1
Brea Canyon	0.9225	21.82	10,418	18,752	144,123	7.6861	11.0	40.0	16.0	Tr.	0.87	0.1	99.9	0.1	23.1	24.5	10.9	1.2	40.2
Puente Hills	0.8911	27.16	10,592	19,066	141,543	7.4242	−2.0	18.0	3.1	Tr.	0.38	0.8	99.2	0.8	32.3	23.1	10.3	1.2	32.3
Whittier	0.9386	19.20	10,449	18,808	147,062	7.8197	46.0	84.0	34.6	0.0	0.61	0.0	100.0	0.0	17.1	30.1	12.6	0.6	39.6
Coyote Hills	0.9052	24.68	10,542	18,974	143,102	7.5422	27.0	50.0	10.5	Tr.	1.14	0.0	100.0	0.0	18.2	26.4	10.4	1.0	44.0
Newhall	0.9245	21.93	10,469	18,845	145,019	7.7026	60.0	83.0	118.2	0.2	0.35	0.1	99.7	0.1	23.0	27.7	10.8	0.8	37.3
Piru	0.9143	23.29	10,336	18,604	141,642	7.6175	23.0	47.0	47.0	0.2	0.67	0.4	99.4	0.4	21.7	28.1	11.1	0.6	37.9
Bardsdale	0.9182	22.56	9,615	17,307	132,214	7.6501	−1.0	30.0	22.5	4.2	1.86	1.8	94.0	1.8	16.7	25.7	9.8	0.7	41.1
Sespe	0.8950	26.47	10,556	19,001	141,676	7.4572	18.0	40.0	10.8	0.4	0.34	1.1	98.5	1.1	22.0	27.5	10.8	1.2	37.0
Santa Paula	0.9022	25.32	10,463	18,834	141,543	7.5169	6.0	18.0	5.8	0.5	0.54	1.2	98.3	1.2	25.4	27.2	10.9	0.7	34.1
Adams Canyon	0.9203	22.16	10,524	18,943	145,233	7.6678	38.0	55.0	11.3	Tr.	0.60	0.0	100.0	0.0	17.7	30.6	11.8	0.7	39.3
Wheeler Canyon	0.8875	27.75	10,529	18,952	140,137	7.3943	−12.0	2.0	2.3	None	0.52	1.3	98.7	1.3	28.6	25.4	9.9	1.0	33.8
Summerland	0.9652	15.06	10,302	18,544	149,106	8.0414	100.0	130.0	222.1	1.2	0.36	0.0	98.8	0.0	1.2	39.8	14.7	0.5	42.6
Santa Maria	0.9053	24.68	10,400	18,720	141,187	7.5429	−2.0	20.0	19.0	0.1	1.93	2.0	97.9	2.0	26.1	22.5	9.2	1.5	38.6
Lompoc	0.9343	19.85	10,186	18,334	142,719	7.7845	−1.0	21.0	62.5	0.7	3.55	0.0	99.3	0.0	17.0	18.4	7.5	1.1	55.3
Arroyo Grande	0.9745	13.66	10,208	18,374	149,185	8.1191	109.0	154.0	1,322.2	0.2	1.11	0.0	99.8	0.0	0.0	29.1	11.2	0.4	59.1
Coalinga	0.9385	19.26	10,310	18,558	145,107	7.8190	70.0	93.0	80.7	0.4	0.48	0.0	99.6	0.0	7.6	37.2	14.2	0.5	40.1
Midway	0.9324	20.30	10,420	18,755	145,253	7.7498	54.0	83.0	91.7	0.6	0.66	0.0	99.4	0.0	15.9	33.5	13.2	0.7	36.1
Sunset	0.9421	18.67	10,392	18,706	146,743	7.8496	47.0	79.0	120.5	0.5	0.76	0.3	99.2	0.3	14.6	30.3	11.8	0.9	41.6

[1] For the sake of brevity, only the *average* commercial values of the petroleums according to districts are given; for values of *all* the samples examined, *Technical Paper 74, Bureau of Mines*, 1914, should be consulted.

TABLE XXIX.—RESULTS OF EXAMINATION OF PETROLEUMS FROM VARIOUS OTHER STATES.

ANALYSES OF PETROLEUM FROM COLORADO

Location of well	Specific gravity at 15°C.	Distillation by Engler's method: Begins to distil at (°C.)	By volume: To 150°C. Cubic centimeters	To 150°C. Specific gravity	150°–300°C. Cubic centimeters	150°–300°C. Specific gravity	Residuum Cubic centimeters	Residuum Specific gravity	Total Cubic centimeters	Sulphur (per cent.)	Paraffin (per cent.)	Asphalt (per cent.)	Water (per cent.)	Unsaturated hydrocarbons (per cent.) Crude	Unsaturated hydrocarbons 150°–300°C.	Remarks
Boulder County[1]	0.8304	......	16.0	0.7368	40.0	0.8000	44.0	....	100.0	....	....	....	....	......	....	Burning oil, 150°F. fire test.
Fremont County, Florence	0.8696	......	......	......	35–40	......	......	......	......	....	10.4	....	....	19.0	....	Fixed carbon, 1.6; character of residuum, soft; loss, 200°C. (7 hr.), 2.4 per cent.
Do.[2]	0.8750	122	1.5	....	27.0	0.7988	70.2	0.9079	98.7	....	9.23					
Mesa County.[3]																
Debeque	0.8345	145	1.0	....	42.0	0.7188	56.5	0.8427	93.5	....	19.65	....	....	12.4	4.0	
Three-fourths mile northwest of Debeque	0.8997	225	......	....	27.0	0.7471	70.9	0.8511	97.9	....	27.23					
Rio Blanco County.[3]																
Rangely, sec. 21, T. 2 N., R. 102 W	0.8092	48	28.0	0.680	42.0	0.751	30.0	....	100.0							

[1] *Mineral Resources of the United States*, **1901**, 560. [2] RICHARDSON, *Petrol. Rev.*, Nov. 24, **1896**.
[3] DAY, *Mineral Resources of the United States*, **1913**, ii, 1178.

ANALYSES OF PETROLEUM FROM ILLINOIS

Location of well	Specific gravity at 15°C.	Begins to distil at (°C.)	To 150°C. Cubic centimeters	To 150°C. Specific gravity	150°–300°C. Cubic centimeters	150°–300°C. Specific gravity	Residuum Cubic centimeters	Residuum Specific gravity	Total Cubic centimeters	Sulphur (per cent.)	Paraffin (per cent.)	Asphalt (per cent.)	Water (per cent.)	Crude	150°–300°C.	Remarks
Clark County. Johnson Township:[1] Weaver lease, sec. 23.	0.8872	88	4.4	0.7450	33.2	0.8120	62.4	....	100.0	0.13	....	....	....	......	....	Sp. gr. of lubricating oil, 0.863; coke and loss, 12.4 per cent.

TABLE XXIX. (*Cont.*).—ANALYSES OF PETROLEUM FROM ILLINOIS.—*Cont.*

W. D. Misner lease; Pure Oil Co.	0.8631	75	11.5	0.7318	35.0	0.8174	53.5	....	100.0	....	....	....	....	....	....	Lower sand oil.
M. Misner lease; Pure Oil Co.	0.8660	75	8.0	0.7193	32.0	0.8065	60.0	....	100.0	0.30	....	....	....	....	....	Do.
Z. E. Brant farm, sec. 26; Ohio Oil Co.	0.8680	75	10.5	0.7261	30.5	0.8141	59.0	....	100.0	0.27	....	....	....	....	....	Upper sand oil.
Do	0.8700	75	10.0	0.7275	33.0	0.8186	57.0	....	100.0	0.24	....	....	....	....	....	Do.
Ohio Oil Co., Martinsville	0.8780	70	10.0	0.7326	33.0	0.8183	57.0	....	100.0	0.23						
Northern part; Ohio Oil Co., Martinsville	0.8761	80	11.0	0.7371	29.5	0.8147	59.5	....	100.0	0.26						
Parker Township: Briscoe lease, sec. 29	0.8730	......	8.6	0.741	34.8	0.8138	56.6	....	100.0	0.73	....	....	....	....	....	Sp. gr. of lubricating oil, 0.853; coke and loss, 8.6 per cent.
Oil-field pool—																
S. Spellbring farm, sec.7; Ohio Oil Co.	0.8460	63	14.0	0.7745	31.0	0.8145	55.0	....	100.0	0.48						
M. K. Young farm, sec. 18; Ohio Oil Co.	0.8460	55	10.5	0.7357	34.0	0.8184	55.5	....	100.0	0.35						
G. H. Jeffries farm, sec. 20; Ohio Oil Co.	0.8530	55	15.5	0.7323	30.5	0.8173	54.0	....	100.0	0.47						
Parker Township pool—																
J. Turner lease, sec. 33; Ohio Oil Co.	0.8790	65	8.5	0.7557	25.0	0.8278	66.5	....	100.0	0.30						
Do	0.8790	65	8.0	0.7008	27.0	0.8268	65.0	....	100.0	0.37						
Kelly farm, sec. 33; Treat & Crawford	0.8650	75	11.5	0.7433	30.5	0.8193	58.0	....	100.0	0.48						
N. J. Linn farm; Mars Oil & Gas Co.	0.8568	65	14.0	0.7473	25.0	0.8216	61.0	....	100.0	0.38						

[1] GROUT, *Ill. State Geol. Survey, Bull.* No. 2.

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM ILLINOIS.—*Cont.*

Location of well	Specific gravity at 15°C.	Begins to distil at (°C.)	Distillation by Engler's method: By volume: To 150°C. Cubic centimeters	To 150°C. Specific gravity	150°–300°C. Cubic centimeters	150°–300°C. Specific gravity	Residuum Cubic centimeters	Residuum Specific gravity	Total Cubic centimeters	Sulphur (per cent.)	Paraffin (per cent.)	Asphalt (per cent.)	Water (per cent.)	Unsaturated hydrocarbons (per cent.) Crude	Unsaturated hydrocarbons (per cent.) 150°–300°C.	Remarks
Casey Township:																
Ohio Oil Co., Casey	0.8299	85	8.0	0.7222	33.0	0.7833	56.1	0.8861	97.1							
Crawford County.																
Oblong Township:[1]																
Birch lease	0.8700	60	3.5	0.749	36.8	0.8060	59.7	....	100.0	0.10	.....	.....	.....	.....	....	Sp. gr. of lubricating oil, 0.849; coke and loss, 9.5 per cent.
Robinson pool:																
Mitchell Oil Co.	0.8460	80	8.0	0.7183	39.0	0.7941	53.0	....	100.0	0.16						
Graswald lease; G. E. Thomas	0.8542	60	16.0	0.733	34.0	0.8135	50.0	....	100.0	0.17						
Miller lease; Fisher Oil Co.	0.8712	80	11.5	0.7531	32.0	0.8266	56.5	....	100.0	0.19						
Quick lease; John Markham	0.8380	51	20.0	0.7705	32.0	0.8107	48.0	....	100.0	0.15						
E. E. Newlin farm, 2½ miles west of Robinson	0.8375	69	13.0	0.728	33.0	0.7954	52.1	0.9132	98.1	....	2.57	0.74	([a])	.....	....	([a]) Present.
Montgomery Township:																
Duncansville pool, J. W. Creswell	0.9150	80	1.0	....	24.5	0.8391	74.5	....	100.0	0.39						
Higgins lease; M. Bernstein Co.	0.9192	75	4.0	....	20.0	0.8507	76.0	....	100.0	0.39						

[1] *Ibid.* For further information see BLATCHLEY'S "Oil Fields of Crawford and Lawrence Counties," *Ill. State Geol. Survey*, **1914**. See also BLATCHLEY'S "Plymouth Oil Field," *Ill. State Geol. Survey*, **1914**.

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM ILLINOIS.—*Cont.*

Martinsville, Ohio, Oil Co.	0.8552	75	15.0	0.7338	37.0	0.8103	48.0	....	100.0	0.17						
W. C. Jones, Robinson, N.W. cor. N. W. ¼ sec. 28, T. 7, R. 2	0.8490	95	13.0	0.7386	37.0	0.8028	50.0	0.9235	100.0	....	3.71	1.56				
Cumberland County.																
Union Township:																
Queen farm, sec. 13	0.8390	60	18.0	0.7211	38.0	0.8146	44.0	....	100.0	0.20	....	....	....	....	....	Oil from first sand.
Underwood lease, sec. 13, Ohio Oil Co.	0.8780	80	10.1	0.719	34.0	0.8215	55.9	....	100.0	0.33	....	....	....	....	....	Lower sand oil contains 8 per cent. water.
Siggins pool, Ohio Oil Co., Martinsville	0.8690	80	13.0	0.7268	33.0	0.7983	54.0	....	100.0	0.19						
Lawrence County.																
Petty Township:																
Bridgeport pool—																
W. E. Neil lease; Braden Oil Co.	0.8330	......	21.0	0.7106	33.0	0.811	46.0	....	100.0	0.17	....	5.04	....	....	....	Lower Bridgeport sand.
Eshelman lease; Bridgeport Oil Co.	0.8542	47	15.0	0.7175	32.0	0.8211	53.0	....	100.0	0.24	....	....	....	....	....	Upper sand.
Do.	0.8642	70	14.5	0.7197	31.0	0.8218	54.5	....	100.0	....	....	....	....	....	....	Do.
Thorn lease; Ohio Co.	0.8552	75	16.5	0.7193	31.0	0.794	52.5	....	100.0	....	....	....	....	....	....	Buchanan sand.
Do.	0.8552	68	16.5	0.7265	41.0	0.8193	42.5	....	100.0	0.20	....	....	....	....	....	Do.
Do.	0.8563	75	14.0	0.7248	32.0	0.8188	54.0	....	100.0	0.21	....	....	....	....	....	Do.
Macpherson lease (100 acres); Kirkwood Oil Co.	0.8280	45	21.0	0.7313	25.0	0.8103	54.0	....	100.0	0.13						

TABLE XXIX. (*Cont.*).—ANALYSES OF PETROLEUM FROM ILLINOIS.—*Cont.*

Location of well	Specific gravity at 15°C.	Begins to distil at (°C.)	Distillation by Engler's method, by volume: To 150°C., Cubic centimeters	To 150°C., Specific gravity	150°–300°C., Cubic centimeters	150°–300°C., Specific gravity	Residuum, Cubic centimeters	Residuum, Specific gravity	Total, Cubic centimeters	Sulphur (per cent.)	Paraffin (per cent.)	Asphalt (per cent.)	Water (per cent.)	Unsaturated hydrocarbons (per cent.): Crude	Unsaturated hydrocarbons (per cent.): 150°–300°C.	Remarks
Macpherson lease (20 acres); Kirkwood Oil Co.	0.8260	40	23.0	0.7113	31.5	0.8101	45.5	....	100.0	0.17						
Snowden Bros. & Co. Bridgeport	0.8309	......	16.8	....	31.2	....	52.0	....	100.0	....	.....	....	....	......	....	From statistical report to U. S. Geological Survey in 1907.
Geo. Cooper farm, Indian Refining Co., Lawrenceville	0.8475	110	6.0	0.7480	40.0	0.7944	54.2	0.9021	100.2	....	1.96	....	Tr.	......	....	Green oil sand.
Ohio Oil Co., Martinsville	0.8470	71	15.0	0.7276	34.0	0.8053	51.0	....	100.0	0.17						
Bridgeport Township: Cummings farm, Indian Refining Co., Lawrenceville	0.8289	73	12.0	0.7230	35.0	0.7874	49.2	0.9067	96.2	....	4.31	....	Tr.	......	....	Do.
Lawrence Township: R. M. Kirkwood farm, Indian Refining Co., Lawrenceville	0.8378	90	13.0	0.7305	32.0	0.7844	51.9	0.9044	96.9	....	3.30	....	Tr.	......	....	Do.
Macoupin County.																
Rinaker & Rinaker	0.8917	155	......	....	21.0	0.8283	74.7	0.9530	98.7	....	.....	....	2.74			
Marion County.																
Near Junction City, N-W. ¼ sec. 32, T. 2 N., R. 1 E.	0.8557	95	6.5	0.7390	34.0	0.7815	57.3	0.9168	97.8	....	4.21	0.53				

TABLE XXIX. (*Cont.*).—ANALYSES OF PETROLEUM FROM ILLINOIS.—*Cont.*

Near Junction City.—*Cont.*	0.8626	108	3.5	0.7430	36.5	0.7887	59.2	0.9132	99.2	....	5.48	0.38				
Montgomery County.																
Litchfield[1]	0.9236	110	1.3	([a])	16.9	0.852	81.8	....	100.0	....	....	....	....	....	....	Sp. gr. of lubricating oil, 0.863; coke and loss, 10.7 per cent; sample out of ground some months. ([a]) Specimens too small to test.
Randolph County.																
Sparta[1]	0.8420	......	14.0	0.729	37.0	0.7972	49.0	....	100.0	....	....	....	....	....	....	Sp. gr. of lubricating oil, 0.850; coke and loss, 7 per cent.; sample had stood some time; burning point, 22°C.

[1] GROUT, *Ill. State Geol. Surv., Bull.* 2.

ANALYSES OF PETROLEUM FROM INDIANA

Dubois County, Birdseye[1]	0.8500	......	17.4	....	26.9	....	55.5	....	99.8	....	....	....	....	....	....	Lubricating oil, 42.2 per cent.; residuum, 13.3 per cent.; sample from Southern Oil Co., Evansville, Ind.

[1] *Ind. Dept. Geol. and Nat. Res. Reports*, 1903.

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM INDIANA.—*Cont.*

Location of well	Specific gravity at 15°C.	Distillation by Engler's method									Sulphur (per cent.)	Paraffin (per cent.)	Asphalt (per cent.)	Water (per cent.)	Unsaturated hydrocarbons (per cent.)		Remarks
		Begins to distil at (°C.)	By volume														
			To 150°C.		150°-300°C.		Residuum		Total								
			Cubic centimeters	Specific gravity	Cubic centimeters	Specific gravity	Cubic centimeters	Specific gravity	Cubic centimeters						Crude	150°-300°C.	
Grant County, Van Buren[1]	0.8531	......	7.2	0.719	32.6	0.7965	60.2	......	100.0	0.83	....	....	....	.....	....	300° - 350°C., 14.8 per cent.; sp. gr., 0.844; 350° - 390°C., 41.8 per cent.; sp. gr., 0.8600.
Jasper County[2]	0.9280	......	.....	....	.....	......	97.0	....	97.0	1.26	....	2.9	....	.....	....	Cold test, 7°F.; fire test, 437°F.
Do[3]	0.9371	248	.....	....	.....	......	......	....	100.0	....	....	47.0	....	.....	....	Total distillates obtained when running crude down to asphalt, 49 per cent.; loss, 4 per cent.
Vigo County, Terre Haute[4]	0.8790	......	.....	....	39.6	0.8254	60.4	....	100.0	0.72	....	....	....	.....	....	300°-350°C., 14.8 per cent.; sp. gr., 0.867; 350°-390°C., 40.6 per cent.; sp. gr., 0.879.

[1] NOYES, *idem*, 1901.
[2] MARINER and HOSKINS, *idem*, 1903.
[3] LEVERING, *idem*, 1904.
[4] NOYES, *idem*, 1901.

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM KANSAS

Allen County.															
Humboldt pool:															
McKinley Crude Oil Co., Humboldt.......	0.8878	123	1.0	....	29.0	0.8152	68.9	0.9247	98.9	....	3.93	2.33	....	32.8	2.0
McKinley Crude Oil Co., Humboldt, Logan Township............	0.8895	110	3.0	....	29.0	0.8142	67.0	0.9284	99.0	....	1.92	2.86	....	23.6	6.0
Fussman lease, Logan Township, Frank Fussman, Humboldt..	0.8822	108	5.0	0.7460	26.5	0.8205	67.4	0.9272	98.9	....	2.10	1.03	....	29.6	
Do.................	0.8850	85	3.5	0.7515	27.0	0.8160	67.2	0.9284	97.7	....	7.92	0.39	....	41.2	8.0
Chanute pool:															
Hedrich lease, I. N. Knapp, Chanute......	0.8706	125	3.0	0.7500	37.5	0.8029	59.3	0.9229	99.8	....	3.78	0.89	....	26.0	1.0
Beach lease, Rex Oil and Gas Co., Chanute.	0.8647	109	5.0	0.7350	36.0	0.7993	57.8	0.9223	98.8	....	4.25	1.23	....	24.0	1.0
Do................	0.8647	110	6.0	0.7375	36.0	0.7992	56.6	0.9204	98.6	....	4.71	1.45	....	22.4	
Kansas Coöperative Refining Co., Chanute.	0.8615	90	7.5	0.7156	33.0	0.8022	58.7	0.9192	99.2	....	1.45	1.50	....	24.0	8.0
Chanute Refining Co., Chanute............	0.8637	113	4.5	0.7405	35.0	0.7927	57.2	0.9174	96.7	....	4.32	1.15	....	24.4	8.0
Moran pool:															
Carroll lease, Eastern Kansas Oil Co., Moran.	0.8794	95	8.0	0.7275	29.0	0.8137	61.0	0.9358	98.0	....	1.21	2.63	....	19.6	3.0
Smith lease, Eastern Kansas Oil Co., Moran.	0.8799	78	10.0	0.7105	25.5	0.8125	64.5	0.9180	100.0	....	3.48	1.66	....	29.2	
Newton lease, E. F. Holman, Moran......	0.8712	75	7.5	0.7190	25.0	0.8135	60.3	0.9409	92.8	....	3.94	2.67	....	28.0	
Eastern Kansas Oil Co., Moran..........	0.8589	106	3.0	0.7330	37.0	0.7822	59.5	0.9192	99.5	...	4.61	2.32	....	27.6	6.0

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM KANSAS.—*Cont.*

Location of well	Specific gravity at 15°C.	Begins to distil at (°C.)	Distillation by Engler's method, by volume: To 150°C. Cubic centimeters	To 150°C. Specific gravity	150°–300°C. Cubic centimeters	150°–300°C. Specific gravity	Residuum Cubic centimeters	Residuum Specific gravity	Total Cubic centimeters	Sulphur (per cent.)	Paraffin (per cent.)	Asphalt (per cent.)	Water (per cent.)	Unsaturated hydrocarbons (per cent.) Crude	Unsaturated hydrocarbons (per cent.) 150°–300°C.	Remarks
Chautauqua County.																
Peru pool:																
Prairie Oil & Gas Co., Peru station, Independence	0.8526	87	7.0	0.7244	32.5	0.7934	58.7	0.9150	98.2	....	3.81	0.35	....	27.6	5.0	
F. G. Hill's lease, Interstate Oil & Gas Co., Peru	0.8557	110	7.0	0.7310	37.0	0.7975	53.2	0.9150	97.2	....	5.79	1.53	....	24.8		
Hill's lease, Central Pool Oil Co., Peru	0.8521	80	12.0	0.7160	30.0	0.7945	55.5	0.9138	97.5	....	5.24	0.20	....	24.8	3.0	
Interstate lease, Pittsburgh Oil & Gas Co., Peru	0.8454	77	11.0	0.7218	30.0	0.7988	55.3	0.9162	96.3	....	4.54	0.42	....	12.4	6.0	
Do	0.8500	66	13.0	0.7177	31.5	0.8015	52.5	0.9174	97.0	....	5.41	0.34	....	......	3.0	
Elk County.																
Longton pool:																
Allen County Investment Co., Longton	0.8637	98	12.0	0.7202	27.5	0.7920	59.3	0.9229	98.8	....	7.19	0.89	....	29.6	5.0	
Do	0.8631	96	6.0	0.7360	31.0	0.7890	59.6	0.9198	96.6	....	4.30	1.56	....	30.8		
Franklin County.																
Rantoul pool:																
Springer lease, Hardison & Streeter, Rantoul	0.8557	76	11.5	0.7116	29.5	0.7950	54.9	0.9272	95.9	....	3.45	2.29	....	34.0		
Tullows lease, Hardison & Streeter, Rantoul	0.8750	136	1.0	....	39.0	0.7892	60.0	0.9358	100.0	....	3.98	2.80	....	26.0	2.0	

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM KANSAS.—*Cont.*

Prairie Oil & Gas Co., Pump station, Rantoul	0.8578	103	5.5	0.7220	33.5	0.7850	59.7	0.9217	98.7	....	4.34	1.93	....	26.4	6.0	
Kay County.[1]																
Newkirk Gas & Mineral Co., Newkirk	0.8511	....	....	....	....	....	....	....	100.0	....	....	....	....	....	....	Below 170°C., 9.1 per cent.; 170°–315°C., 43.75 per cent.; lubricating oil, 37 per cent.; solid oil and residuum, 10.15 per cent.
Miami County.																
Paola pool:																
C. J. Hafey, Paola	0.8511	80	10.0	0.7202	33.0	0.7964	55.8	0.9223	98.8	....	7.44	2.94	....	19.6	8.0	
Montgomery County.																
Coffeyville pool:																
Gilroy lease, Brown Brokerage Co., Coffeyville	0.8822	173	....	....	31.0	0.8082	66.2	0.9138	97.2	....	5.31	0.17	....	22.0		
M. Davis lease, Dunkley & Odell, Coffeyville	0.8717	100	6.0	0.7289	33.0	0.8030	58.3	0.9241	97.3	....	....	....	....	24.4		
Wayside pool:																
J. Hall lease, Lynch & McSweeney, Wayside	0.8696	75	9.5	0.7100	28.0	0.8080	59.9	0.9396	97.4	....	4.66	0.61	....	35.6		
Do	0.8838	81	5.0	0.7315	28.0	0.7962	66.0	0.9290	99.0	....	....	....	....	50.0	8.0	
Bolton pool:																
G. L. Bank lease, Miler, Rider & Co., Independence	0.8424	72	14.7	0.7273	31.0	0.8095	49.2	0.9365	94.9	....	....	....	....	20.0		

[1] *Mineral Resources of the U. S.*, **1903**, 671.

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM KANSAS.—*Cont.*

Location of well	Specific gravity at 15°C.	Distillation by Engler's method: Begins to distil at (°C.)	By volume: To 150°C. Cubic centimeters	To 150°C. Specific gravity	150°–300°C. Cubic centimeters	150°–300°C. Specific gravity	Residuum Cubic centimeters	Residuum Specific gravity	Total Cubic centimeters	Sulphur (per cent.)	Paraffin (per cent.)	Asphalt (per cent.)	Water (per cent.)	Unsaturated hydrocarbons (per cent.): Crude	Unsaturated hydrocarbons (per cent.): 150°–300°C.	Remarks
Prairie Oil & Gas Co., Station 5, Independence	0.8495	109	7.0	0.7358	36.5	0.7982	55.6	0.9126	99.1	....	6.31	0.55	....	24.0	6.0	
Federal Gas & Oil Co., Cherryvale[1]	0.8730	......	.....	....	....	....	....	....	.....	.....	.....	.....	.....	.....	....	Distillation *in vacuo*, 20 mm. pressure, 60°–140°C., 16.3 per cent.; 140°–300° C., 53.9 per cent. Character of residuum at 200° C., soft, paraffin; 280°–300°C., solid.
Neosho County.																
Erie pool:																
Webb lease, Northland Oil & Gas Co., Erie	0.8739	135	1.0	....	34.0	0.8000	64.1	0.9115	99.1	....	4.78	3.20	....	27.2	7.0	
Barger lease, Buckeye Oil & Gas Co., Erie	0.8658	110	3.0	....	35.0	0.7960	61.8	0.9162	99.8	....	1.22	0.88	....	23.6	2.0	
Thayer[2]	0.8490	......	16.7	0.7282	39.2	0.8093	44.1	0.8663	100.0							
Wilson County.																
Neodesha pool:																
D. Johnson lease, Dolly Johnson Oil & Gas Co., Neodesha	0.8373	80	17.0	0.7172	30.0	0.8005	48.6	0.9079	95.6	....	....	....	....	18.0		

[1] *Petrol. Rev.*, Feb. 2, 1907. [2] BAILEY, *Mineral Resources of Kansas*, 1897.

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM KANSAS.—*Cont.*

T. Johnson lease, Prairie Oil & Gas Co., Neodesha	0.8368	88	16.0	0.7158	36.0	0.7925	47.7	0.9091	99.7	....	3.40	0.08	....	20.0		
Dolly Johnson Oil & Gas Co., Neodesha	0.8568	135	1.0	....	40.5	0.7994	57.0	0.9109	98.5	....	5.79	0.10	....	30.0	3.0	
Neodesha	0.8350	......	19.1	0.7205	38.1	0.8081	42.8	....	100.0							
Do	0.8350	......	19.8	0.7252	34.8	0.8105	45.4	....	100.0							

ANALYSES OF PETROLEUM FROM KENTUCKY

Allen County.																
Petroleum pool, Newman farm, Southern Oil & Gas Co., Petroleum	0.8490	71	12.5	0.7373	41.0	0.8144	45.3	0.9162	98.8	....	3.65	2.10	Tr.	18.8	0.7	
Bath County.																
Ragland pool, Ragland farm, J. W. Radcliffe	0.8963	136	1.0	....	29.0	0.8151	69.6	0.9434	99.6	....	2.13	0.0	Tr.	30.0	5.0	Ragland sand.
Lawrence County.																
Lower Lawrence County[1]	0.8531	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	Submitted to distillation until 91.4 per cent. passed over; distillate then fractionally distilled, 160°C., 16.3 per cent. of original; 160°–320° C., 39 per cent.

[1] *Ken. Geol. Survey*, 1888.

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM KENTUCKY.—*Cont.*

Location of well	Specific gravity at 15°C.	Distillation by Engler's method: Begins to distil at (°C.)	By volume: To 150°C. Cubic centimeters	To 150°C. Specific gravity	150°–300°C. Cubic centimeters	150°–300°C. Specific gravity	Residuum Cubic centimeters	Residuum Specific gravity	Total Cubic centimeters	Sulphur (per cent.)	Paraffin (per cent.)	Asphalt (per cent.)	Water (per cent.)	Unsaturated hydrocarbons (per cent.): Crude	Unsaturated hydrocarbons (per cent.): 150°–300°C.	Remarks
Busseyville 1	0.8104	70	9.5	0.7245	34.5	0.7756	49.4	0.8861	93.4							
Busseyville 2	0.8187	70	7.5	0.7100	38.0	0.7759	49.5	0.8923	95.0							
Busseyville 3	0.8226	73	13.0	0.7156	33.0	0.7854	49.0	0.8917	95.0							
Morgan County.																
Buck Run field, Union Township, sec. 11, Harrison farm	0.8092	95	13.0	0.7270	35.0	0.7796	50.7	0.8557	98.7	....	5.40	0.0	....	8.4	6.8	First Cow Run sand.
Ohio County.																
West Kentucky Oil Co., Hartford	0.8383	70	7.0	0.707	32.0	0.7802	57.4	0.9201	96.4	....	3.6	0.0	Tr.			
Wayne County.																
Parnell pool, Polly Lair farm, P. M. Burwald, Monticello	0.8083	43	27.0	0.7047	33.0	0.8017	37.3	0.9061	97.3	....	2.47	0.0	....	14.8	6.0	Sunnybrook sand.
Sinking pool, Wood Oil Co., Monticello	0.8154	65	22.0	0.7273	36.0	0.8043	38.6	0.9038	96.6	....	3.73	0.56	....	11.6	2.0	Beaver Creek sand.
Oil Valley pool, Ohio & Kentucky Oil Refining Co., Oil Valley	0.8154	50	20.0	0.7129	36.0	0.7989	39.7	0.9121	95.7	....	3.34	1.78	....	14.8	2.0	Do.
Johnson Fork field	0.8408	53	13.5	0.7201	32.0	0.7980	49.9	0.9235	95.4	....	3.01	2.66	....	31.2	4.0	
....	0.8235	60	16.5	0.7187	32.0	0.7934	46.9	0.9056	95.4	....	4.57	0.0	....	18.8	7.0	

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM KENTUCKY.—*Cont.*

Cooper pool, B. S. Huffaker farm, Penn Lubricating Co., Monticello	0.8178	35	25.0	0.7155	29.0	0.8062	42.1	0.9186	96.1	....	2.65	0.80	....	14.4	14.0	Beaver Creek sand.
Turkey Rock pool, Slickford district, Jos. Brown & Co., Slickford	0.8163	60	23.0	0.7181	36.0	0.7947	40.2	0.9038	99.2	....	2.31	0.36	....	15.6	14.0	
Rocky Branch pool (near Monticello), Grant Roberts farm. Dempsey Oil Co., Bradford, Pa., first oil from well	0.9021	170	......	....	26.0	0.8183	73.0	0.9259	99.0	....	5.49	....	Tr.	63.0	3.0	
Parmleysville pool (north end), James Burnett farm, Ross Wetsel & Co., Parmleysville	0.8348	76	13.0	0.7174	36.0	0.7959	47.9	0.9115	96.9	....	5.09	....	Tr.	2.0	5.0	Do.
H. M. Caldwell, Monticello	0.8211	67	16.0	0.7148	37.5	0.9979	41.2	0.9150	94.7	....	4.93	0.41				
Warren County.																
Sunnyside[1]	0.8426	67	19.0	....	37.0	....	44.0	....	100.0	....	....	....	....	....	....	Volatility in open dish, 150°C. (7 hours), 40.7 per cent.; 160°C., 44.5 per cent.; 200°C., 58 per cent. To constant weight, 150°C. (42 hr.), 70.6 per cent.; 160°C. (7 hr.), 73.8 per cent.

[1] RICHARDSON, *Petrol. Rev.*, Oct. 27, 1906.

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM LOUISIANA—*Cont.*

Location of well	Specific gravity at 15°C.	Distillation by Engler's method: Begins to distil at (°C.)	By volume: To 150°C. Cubic centimeters	To 150°C. Specific gravity	150°–300°C. Cubic centimeters	150°–300°C. Specific gravity	Residuum Cubic centimeters	Residuum Specific gravity	Total Cubic centimeters	Sulphur (per cent.)	Paraffin (per cent.)	Asphalt (per cent.)	Water (per cent.)	Unsaturated hydrocarbons (per cent.) Crude	Unsaturated hydrocarbons (per cent.) 150°–300°C.	Remarks
Caddo Parish.																
Hostetter farm, Mooringsport............	0.8187	138	3.0	......	55.0	0.7778	40.4	0.8866	98.4	....	1.70	0.09				
Caddo Oil & Mineral Co.	0.8264	136	1.5	......	49.0	0.7778	49.1	0.8805	99.6	....	5.30	0.25				
Frank Filer Lease, NW. ¼ SE. ¼ sec. 7, T. 15, R. 20...............	0.9211	200	......	......	12.0	0.8510	82.9	0.9061	94.9	....	7.78	0.91	....	.....	....	Contains water.
Old Caddo Oil & Gas Co., E. K. Smith's land................	0.8723	210	......	......	28.0	0.8299	69.5	0.8895	97.5	....	7.32	0.14	....	.....	....	Do.
NW. ¼ NW. ¼ sec. 7, T. 15, R. 20..........	0.8929	173	......	......	20.0	0.8408	79.0	0.9061	99.0	....	5.29	0.50	....	.....	....	Do.
Black Bayou Oil Co., SW. ¼ sec. 10, T. 15, R. 20...............	0.9150	210	......	......	18.0	0.8450	81.2	0.9138	99.2	....	.....	0.24	....	.....	....	Do.
1 mile southeast of Vivian, NW. ¼ NE. ¼ sec. 36, T. 22 N., R. 16 W.................	0.9253	265	......	......	17.0	0.8406	82.9	0.9302	99.9	....	.....	0.22	....	.....	....	Do.
Caddo Oil & Gas Co., E. K. Smith's farm...	0.9211	200	......	......	14.0	0.8142	59.0	0.8974	73.0	....	3.64	0.34	20.0	.....	....	0.7 per cent. clay.
Caddo Oil & Gas Co., E. K. Smith's farm. SE. ¼ SW. ¼ sec. 1, T. 16, R. 20...........	0.8889	220	......	......	18.0	0.8406	79.4	0.9003	97.4	....	4.78	0.64	....	.....	....	Much water.

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM LOUISIANA.—*Cont.*

Richardson Oil Co., N-E. ¼ NW. ¼ sec. 32, T. 15 W., R. 21 N.	0.9121	220	......	......	16.5	0.8713	66.6	0.9241	83.1	....	......	0.54	....	......	......	Much water.
Brown Oil Co., Black Bayou	0.9109	248	......	......	10.5	0.8690	88.2	0.9235	98.7							
James Bayou	0.8065	95	15.0	0.7275	47.0	0.7770	40.0	0.8739	102.0	0.0	7.02	....	12.8			
Calcasieu Parish.																
Jennings[1]	0.9093	200	......	......	41.0	......	59.0	......	100.0	0.39	....	5.0	....	......	......	From 300°-350° C., 24 per cent.; 350°C. to asphalt, 30 per cent.; B.t.u., 19,814.
Welsh[1]	0.9276	230	......	......	19.0	......	81.0	......	100.0	0.32	....	9.0	....	......	......	From 300°-350° C., 23 per cent.; 350°C. to asphalt, 49 per cent.; color of fraction, nearly colorless, light yellow on standing; B.t.u., 19,000.
Do[2]	0.9380	Over 91	1.05	0.831	30.07	0.852	68.88	......	100.0	0.0	....	....	....	......	......	Lubricating oil, 65.38 per cent.; coke and loss, 3.5 per cent.; viscosity, 36.8 by Engler's method.
Evangeline Parish.																
Sample No. 1	0.8626	175	......	......	59.0	0.8493	40.0	0.8980	99.0	0.15	0.0	0.0	....	6.8		
Sample No. 2	0.8653	173	......	......	59.0	0.8493	41.0	0.9009	100.0	0.15	0.0	0.0	....	8.8		

[1] COATES and BEST, *J. Am. Chem. Soc.*, **25**, 1154.

[2] *Mineral Resources of the U. S.*, **1905**, 872.

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM LOUISIANA.—*Cont.*

Location of well	Specific gravity at 15°C.	Distillation by Engler's method: Begins to distil at (°C.)	By volume: To 150°C. Cubic centimeters	To 150°C. Specific gravity	150°–300°C. Cubic centimeters	150°–300°C. Specific gravity	Residuum Cubic centimeters	Residuum Specific gravity	Total Cubic centimeters	Sulphur (per cent.)	Paraffin (per cent.)	Asphalt (per cent.)	Water (per cent.)	Unsaturated hydrocarbons (per cent.): Crude	Unsaturated hydrocarbons (per cent.): 150°–300°C.	Remarks
St. Martins Parish. Moresi Co., Anse Le Butte[1]	0.9392	240	......	......	16.0	......	84.0	......	100.0	0.20	.....	9.0	....	.....	.....	B.t.u. 19,300. When residue heated and evaporated in open dish it was hard, black, shiny, with conchoidal fracture; sp. gr., 1.123. Analysis residuum of asphalt showed volatile, 71 per cent.; fixed carbon, 28.6 per cent.; ash, 0.4 per cent.
Robt. Martin, Bayou Bouillon[2]	0.8590	.....	4.3	......	28.4	......	67.3	......	100.0	....	....	....	....	....	....	Above 300°C., lubricating oil, 42 per cent.; asphalt and coke, 15.5 per cent.; loss, 9.8 per cent.

[1] COATES and BEST, *op. cit.* [2] *Bull. U. S. Geol. Survey*, No. 282 (1906).

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM LOUISIANA.—*Cont.*

Bayou Bouillon.—*Cont.*	0.9669	275	......	......	11.0	......	89.0	......	100.0	0.57	....	....	....	......	......	From 300°-350° C., 62 per cent.; color of fraction, yellow; B.t.u., 18,500; residue, asphaltic.
Bayou Laroupe[1]	0.9604	265	......	......	6.0	......	94.0	......	100.0	Low	....	....	....	......	......	From 300°-350° C., 7 per cent.; color of fraction, yellow; residue, asphaltic.

[1] COATES and BEST, *J. Am. Chem. Soc.*, 27, 1317.

ANALYSES OF PETROLEUM FROM MICHIGAN, MISSOURI AND NEW MEXICO

MICHIGAN. *Saginaw County.*																
Saginaw Development Co.	0.8065	98	15.0	0.7251	52.0	0.7854	33.4	0.8834	100.4	....	0.78	0.0	0.0			
St. Clair County.																
Port Huron[1]	0.8333	......	15.0	......	55.0	......	30.0	......	100.0	....	....	....	....	......	......	Lubricating oil, 20 per cent.; tar, 5 per cent.; coke, 5 per cent. (Taken from card reporting production.)
MISSOURI. *Cass County.*																
Belton[2]	......	......	10.0	......	19.0	......	71.0	......	100.0	....	8.0	....	....	......	......	Lubricating oil, 53 per cent.; residue tar, 10 per cent.; with only a trace of organic matter.

[1] *Mineral Resources of the U. S.*, 1905, 879. [2] *Idem*, 1902, 566.

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM MICHIGAN, MISSOURI AND NEW MEXICO.—*Cont.*

Location of well	Specific gravity at 15°C.	Distillation by Engler's method: Begins to distil at (°C.)	By volume: To 150°C.		150°–300°C.		Residuum		Total	Sulphur (per cent.)	Paraffin (per cent.)	Asphalt (per cent.)	Water (per cent.)	Unsaturated hydrocarbons (per cent.)		Remarks
			Cubic centimeters	Specific gravity	Cubic centimeters	Specific gravity	Cubic centimeters	Specific gravity	Cubic centimeters					Crude	150°–300°C.	
NEW MEXICO. *Eddy County.*																
Two miles east of Dayton, 10 miles southeast of Artesia; owned by W. S. Williams.......	0.8951	217	.....	....	30.0	0.8395	68.9	0.9241	98.9	(*a*)	.....	0.56	....	(*a*)	(*a*)	*a* Not determined.
Three miles south of Dayton; A. F. Lucas, Washington, D. C....	0.9186	137	Tr.	....	28.5	0.8564	68.4	0.9444	96.9	(*a*)	0.0	0.0	....	20.0	60.0	Do.
Dayton pool; Roswell Oil Co., Artesia....	0.9168	188	.....	....	28.0	0.8541	72.0	0.9396	100.0	(*a*)	0.0	3.65	....	28.4	12.0	Do.
Do....	0.9109	142	1.0	....	31.0	0.8417	68.1	0.9390	100.1	(*a*)	0.0	3.91	....	25.6	14.0	Do.

ANALYSES OF PETROLEUM FROM OHIO

Location of well	Specific gravity at 15°C.	Begins to distil at (°C.)	To 150°C. Cubic centimeters	To 150°C. Specific gravity	150°–300°C. Cubic centimeters	150°–300°C. Specific gravity	Residuum Cubic centimeters	Residuum Specific gravity	Total Cubic centimeters	Sulphur (per cent.)	Paraffin (per cent.)	Asphalt (per cent.)	Water (per cent.)	Crude	150°–300°C.	Remarks
OHIO. *Allen County.*																
Lima[1]................	0.7910	23	16.0	0.700	68.0	0.788	16.0	....	100.0	....	....	....	....	......	....	Paraffin oil, 6 per cent.; sp. gr., 0.813.
Do[2]................	0.8350	......	10.0	Under 0.730	50.0	....	40.0	....	100.0	....	....	....	....	......	....	Lubricating oil, 30 per cent.; sp. gr., 0.830.

[1] MANDELL and BOURGOUGNON, *J. Am. Chem. Soc.*, **18**, 168.

[2] WOODMAN, *idem*, **18**, 179.

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM OHIO.—*Cont.*

Lima[1]	0.8500	......	......	......	......	......	......	......	......	0.65	......	....	0.7	......	......	Gives naphtha and burning oil, 56.8 per cent.; heavy oil (above 500°F.), 32 per cent.; residuum, 9.6 per cent.
Do[2]	0.8380	......	9.75	0.7282	37.13	0.7871	53.12	......	100.0	0.37	......	......	......	......	......	300°-350°C., 8.63 per cent.; sp. gr., 0.8242; bromine absorption, 6.1 per cent.
Fairfield County.																
Bremen pool, Rush Creek Township; L. Groves farm	0.7848	68	15.0	0.7036	40.0	0.7698	42.0	0.8557	97.0	....	8.33	0.0	(*a*)	11.6	4.0	Clinton sand.
Pleasantville pool, Richland Township; J. G. Ruff farm	0.8046	96	10.0	0.7195	43.0	0.7751	45.8	0.8647	98.8	....	5.36	0.0	(*a*)	10.0	4.0	Do.
Hancock County.																
Findlay, Peerless Refining Co.[3]	0.8380	......	9.75	0.7282	37.13	0.7871	52.13	......	99.01	......	......	......	......	......	......	Bromine absorption of distillate, 110°-150°C., 0.73 per cent.; 150°-220°C., 1.74 per cent.; 220°-257°C., 4.84 per cent.; 257°-300°C., 5.04 per cent.; 300°-330°C., 12.10 per cent.; residuum, 19.50 per cent.

(*a*) None.
[1] WOODMAN, *ibid.*, 180.
[2] MABERY, *J. Frank. Inst.*, Nos. 834 and 835.
[3] MABERY, *Am. Chem. J.*, 17, 714.

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM OHIO.—*Cont.*

Location of well	Specific gravity at 15°C.	Distillation by Engler's method									Sulphur (per cent.)	Paraffin (per cent.)	Asphalt (per cent.)	Water (per cent.)	Unsaturated hydrocarbons (per cent.)		Remarks
		Begins to distil at (°C.)	By volume														
			To 150°C.		150°–300°C.		Residuum		Total								
			Cubic centimeters	Specific gravity	Cubic centimeters	Specific gravity	Cubic centimeters	Specific gravity	Cubic centimeters						Crude	150°–300°C.	
Knox County.																	
Bladenburg pool; Jackson Township........	0.8469	75	14.0	0.7201	26.0	0.7973	56.3	0.9063	96.3	....	4.17	0.0	(*b*)	19.6	7.0	Clinton sand.
Monroe County.																	
Decker pool (near Lewisville), Summit Township, sec. 23; Minard Run Oil Co., Bradford, Pa.; C. B. Buchanan lease................	0.7955	77	18.0	0.7175	38.0	0.7787	42.4	0.8653	98.4	....	2.82	0.0	(*b*)	3.2	3.0	Big Injun sand.
Decker pool (near Lewisville), Summit Township, sec. 23; Henry Dillar farm; W. G. Decker, Washington, Pa.................	0.7982	87	16.0	0.7225	39.0	0.7758	44.9	0.8563	99.9	....	5.47	0.0	(*b*)	2.8	3.0	Keener sand.
Near (250 ft.) Ohio No. 5; Henry Dillar farm; W. G. Decker, Washington, Pa...........	0.7977	97	11.0	0.8255	43.0	0.7896	44.1	0.8531	98.1	....	2.23	0.0	(*b*)	......	8.0	Big Injun sand.
Jerusalem pool, Malaga Township; Unity Oil Co., Woodsfield; Ernest Harper lease.........	0.8373	100	5.0	0.7815	30.0	0.8195	63.6	0.8589	98.6	....	5.65	....	Tr.	24.0	5.0	Keener sand.
Jerusalem pool, Sunsbury Township; W. R. Gatchell lease; Central Gas Co., Woodsfield..	0.7848	55	19.0	0.6837	35.5	0.7696	43.1	0.8568	97.6	....	3.60	0.0	....	6.8	4.0	Lime sand.

(*b*) Much.

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM OHIO.—*Cont.*

Clarington pool, Salem Township; Sterling farm, 2 miles north of Clarington; Consolidated Oil & Gas Co., Pittsburgh, Pa.	0.7968	90	15.0	0.7210	40.0	0.7771	43.7	0.8578	98.7	....	5.65	0.0	....	4.0	4.0	Lime and Keener sands.
Graysville pool, Washington Township; Scarbraugh farm; Pure Oil Co., Woodsfield	0.7782	70	25.0	0.7020	38.0	0.7715	36.7	0.8526	99.7	....	3.35	0.0	....	6.0	2.0	Keener sand.
Olive Township; C. W. Brown farm	0.8260	67	12.0	0.7290	33.0	0.7934	53.5	0.8663	98.5	....	11.24	0.0	....	22.8	5.0	
Griffith pool, Center Township; Markle heirs farm; Pure Oil Co., Woodsfield	0.7937	75	18.5	0.7232	42.0	0.7893	39.3	0.8537	99.8	....	3.56	0.0	....	5.6	5.0	Do.
Bethel Township, sec. 7; Weber farm; Carter Oil Co., Sisterville, W. Va.	0.7739	65	19.0	0.7034	51.0	0.7721	28.5	0.8521	98.5	....	2.91	0.0	....	4.8	5.0	First Cow Run sand.
Morgan County.																
Milner pool; J. W. Calvert farm	0.8046	74	14.5	0.7137	38.5	0.7815	43.6	0.8669	96.6	....	5.36	0.0	....	11.6	5.0	Do.
Milner pool; Milner farm	0.8023	70	19.0	0.7141	37.0	0.7834	43.2	0.8623	99.2	....	5.74	0.0	....	4.4	5.0	Peeker sand.
Noble County.																
Macksburg field, Jefferson Township; Geo. R. Rue farm	0.8154	115	5.0	0.7435	43.0	0.7801	50.0	0.8626	98.0	....	6.15	0.0	....	3.6	3.0	Macksburg 500-ft. sand.
Do.	0.8159	62	15.0	0.7215	30.0	0.7908	51.3	0.8783	96.3	....	4.86	0.0	....	6.0	2.0	Berea sand.
Belle Valley pool, Noble Township; Harry Barnhouse lease; Chris McKee, Belle Valley	0.8240	57	13.0	0.7250	28.0	0.7463	55.8	0.8805	96.8	....	5.44	0.0	....	3.2	4.0	Keener sand.

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM OHIO.—*Cont.*

Location of well	Specific gravity at 15°C.	Distillation by Engler's method: Begins to distil at (°C.)	By volume: To 150°C.: Cubic centimeters	To 150°C.: Specific gravity	150°–300°C.: Cubic centimeters	150°–300°C.: Specific gravity	Residuum: Cubic centimeters	Residuum: Specific gravity	Total: Cubic centimeters	Sulphur (per cent.)	Paraffin (per cent.)	Asphalt (per cent.)	Water (per cent.)	Unsaturated hydrocarbons (per cent.): Crude	Unsaturated hydrocarbons (per cent.): 150°–300°C.	Remarks
Belle Valley pool[1]—*Cont*.	0.8293	85	23.0	0.7297	21.0	0.8014	......	......	......	0.6	......	......	....	5.0	......	Crude oil: carbon, 85 per cent.; hydrogen, 13.80 per cent.; oxygen and nitrogen, 0.60 per cent. Distillate: 300°–350°C., 21 per cent.; sp. gr., 0.8404; refractive index, 1.468; 350°–400° C., 27 per cent.; sp. gr., 0.8643; refractive index, 1.481. Viscosity by P. R. R. pipette, 42.
Perry County.																
San Toy pool, Bearfield Township; McCarty farm; Chapman lease.	0.8240	60	18.0	0.7230	27.0	0.7981	52.2	0.8917	97.2	...	6.16	0.0	Tr.	8.0	5.0	Berea sand.
Crooksville pool, Harrison Township; Ohio Fuel Co. lot	0.8014	98	7.0	0.7215	45.0	0.7736	45.6	0.8663	97.6	...	6.63	0.0	....	10.0	4.0	Clinton sand.

[1] *Bull. U. S. Geol. Survey*, No. 282 (1906).

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM OHIO.—*Cont.*

New Straitsville pool, Coal Township; Clancy lot	0.7923	80	17.5	0.7141	33.0	0.7753	45.7	0.8706	96.2	....	8.30	0.0	....	10.8	6.0	Clinton Sand.
Vinton County.																
Jackson Township, Clinton farm	0.7959	102	4.0	0.7140	51.0	0.7673	43.6	0.8600	98.0	....	5.62	0.0	0.0	5.6	4.0	Do.
Washington County.																
Macksburg, Moseley farm[1]	0.8118	......	[a]15.47	......	[b]45.81	......	......	......	......	......	......	......	......	......	......	Crude oil: carbon 85 per cent.; hydrogen, 13.77 per cent.; nitrogen, 0.027 per cent.; bromine absorption, 7.62 per cent. [a]Up to 160°C.; [b]160°–310°C.
Macksburg, Warren farm[2]	0.8274	......	[a]10.64	......	[b]29.17	......	......	......	......	......	......	......	......	......	......	Crude oil: carbon, 85.42 per cent.; hydrogen, 14.59 per cent.; nitrogen, 0.064 per cent.; bromine absorption, 9.96 per cent. [a]Up to 160°C.; [b]160°–310°C.
Macksburg, J. S. Dunn farm[3]	0.7971	......	[a]20.32	......	[b]31.32	......	......	......	......	......	......	......	......	......	......	Crude oil: carbon, 84.19 per cent.; hydrogen, 14.75 per cent.; nitrogen, 0.015 per cent.; bromine absorption, 9.46 per cent. [a]Up to 160°C.; [b]160°–310°C.

[1] *Am. Chem. J.*, **18**, 218. [2] MABERY and DUNN, *Am. Chem. J.*, **18**, 221. [3] MABERY and DUNN, *ibid.*, 219.

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM OHIO.—*Cont.*

Location of well	Specific gravity at 15°C.	Distillation by Engler's method									Sulphur (per cent.)	Paraffin (per cent.)	Asphalt (per cent.)	Water (per cent.)	Unsaturated hydrocarbons (per cent.)		Remarks
		Begins to distil at (°C.)	By volume														
			To 150°C.		150°–300°C.		Residuum		Total								
			Cubic centimeters	Specific gravity	Cubic centimeters	Specific gravity	Cubic centimeters	Specific gravity	Cubic centimeters						Crude	150°–300°C.	
Macksburg, McLauth farm[1]	0.8205	......	[a]14.12	......	[b]33.27	......	......	......	......		......	......	......	......	......	......	Crude oil: carbon, 84.45 per cent.; hydrogen, 13.79 per cent.; nitrogen, 0.018 per cent.; bromine absorption, 8.45 per cent. [a]Up to 160°C.; [b]160°–310°C.
Macksburg, Moseley farm[2]	0.8138	......	[a]20.69	......	[b]33.08	......	......	......	......		......	......	......	......	......	......	Crude oil: carbon, 84.56 per cent.; hydrogen, 14.33 per cent.; nitrogen, 0.038 per cent.; bromine absorption, 5.93 per cent. [a]Up to 160°C.; [b]160°–310°C.
Archers Fork, Ward farm[3]	0.7939	......	[a]29.65	......	[b]35.32	......	......	......	......		......	......	......	......	......	......	Crude oil: carbon, 84.35 per cent.; hydrogen, 14.72 per cent.; nitrogen, 0.038 per cent.; bromine absorption, 6.25 per cent. [a]Up to 160°C.; [b]160°–310°C.

[1] MABERY and DUNN, *ibid.*, 219. [2] MABERY and DUNN, *ibid.*, 220. [3] MABERY and DUNN, *ibid.*, 225.

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM OHIO.—*Cont.*

Germantown pool, Liberty Township; Hendershot lease, Consolidated Oil & Mining Co.	0.8023	65	16.0	0.7175	35.0	0.7797	45.4	0.8679	96.4	....	6.43	0.0	....	6.0	2.0	First Cow Run sand.
Fifteen pool, Liberty Township	0.7865	60	20.0	0.6970	37.0	0.7716	42.1	0.8537	99.1	....	7.25	0.0	....	12.4	2.0	Maxton sand.

ANALYSES OF PETROLEUM FROM OKLAHOMA[1]

OKLAHOMA.															
Creek County.															
Bird Creek and Skiatook pools:															
Prairie Oil & Gas Co., Tulsa, Bird Creek district	0.8626	120	2.0	....	37.5	0.8070	60.6	0.9003	100.1	....	7.30	0.28	....	29.2	6.0	
N. Chisholm lease, Creek & Indiana Investment Co., Sperry	0.8495	100	7.0	0.7380	38.5	0.8018	52.8	0.9021	98.3	....	2.87	0.62	....	29.2	9.0	
Do.	0.8563	122	Tr.	....	40.5	0.8030	57.0	0.9021	97.5	....	8.41	0.42	....	14.0	11.0	
Skiatook pool:																
Smith lease, Shawnee Oil Co., Sperry	0.8480	95	6.0	0.7348	37.0	0.7898	54.9	0.9032	97.9	....	7.35	0.23	....	14.8	7.0	
Do.	0.8439	98	5.0	0.7440	36.0	0.7858	58.8	0.8997	99.8	....	9.74	0.50	....	12.8	10.0	
Chisholm lease, Shawnee Oil Co., Sperry	0.8328	68	11.0	0.7142	33.5	0.7968	51.8	0.8974	96.3	....	6.65	0.14	....	13.2	10.0	
Glenn pool:																
Grace Berryhill lease, Oklahoma State Oil Co., Kiefer	0.8459	112	7.5	0.7464	42.0	0.7980	50.0	0.9061	99.5	....	5.41	0.11	....	21.2	6.0	

[1] On Oklahoma petroleum, see L. C. SNIDER's "Petroleum and Natural Gas in Oklahoma," 1918.

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM OKLAHOMA.—*Cont.*

Location of well	Specific gravity at 15°C.	Distillation by Engler's method: Begins to distil at (°C.)	By volume: To 150°C. Cubic centimeters	To 150°C. Specific gravity	150°–300°C. Cubic centimeters	150°–300°C. Specific gravity	Residuum Cubic centimeters	Residuum Specific gravity	Total Cubic centimeters	Sulphur (per cent.)	Paraffin (per cent.)	Asphalt (per cent.)	Water (per cent.)	Unsaturated hydrocarbons (per cent.): Crude	Unsaturated hydrocarbons (per cent.): 150°–300°C.	Remarks
Pittman farm, sec. 7, T. 17 N., R. 12, Argue & Compton, Tulsa...	0.8459	105	8.5	0.7566	42.0	0.8001	49.9	0.9032	100.4	...	6.98	0.45	....	22.8	7.0	
Pump station, Prairie Oil & Gas Co., Kiefer.	0.8464	100	4.5	......	46.0	0.7942	49.9	0.9032	100.4	...	5.99	0.24	....	27.6	9.0	
Thos. Berryhill lease, Indiana Oil & Gas Co., Kiefer.............	0.8439	105	8.0	0.7508	44.5	0.8008	48.0	0.9091	100.5	...	7.53	0.90	....	20.8	6.0	
Wm. Berryhill lease, Indiana Oil & Gas Co., Kiefer.............	0.8333	80	11.5	0.7260	43.5	0.7964	45.3	0.9079	100.3	...	11.46	0.35	....	21.6	4.0	
W. B. Self lease, Prairie Oil & Gas Co., Tulsa.	0.8373	94	10.0	0.7328	41.0	0.7968	47.6	0.9021	98.6	...	3.12	0.21	....	16.8	5.0	
Do...............	0.8424	98	10.0	0.7402	42.5	0.7990	47.6	0.9079	100.1	...	9.70	0.51	....	26.4	6.0	
Mounds pool:																
Corndoffer lease, sec. 18, T. 16, R. 12; Swasey Oil Co., Fort Worth, Tex.........	0.8631	175	......	......	38.5	0.8126	59.9	0.8992	98.4	...	8.44	0.62	....	12.4	4.0	
Kiowa County.																
Gotebo pool:																
Ricketts lease, Whitewater Oil & Gas Co., Gotebo.............	0.8480	115	3.5	0.7399	45.5	0.7828	51.5	0.9097	100.5	...	5.56	1.30	....	29.6	15.0	
Seney lease, Deering Oil & Gas Co., Gotebo...	0.8552	128	2.0	......	40.0	0.7884	56.9	0.9186	98.9	...	5.01	0.31	....	57.2	3.0	

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM OKLAHOMA.—*Cont.*

Marshall County.															
Mal-Millan Oil Co., Madill, sec. 5, T. 5 S., R. 5 E.	0.7887	65	22.0	0.7118	38.0	0.7788	36.8	0.8669	96.8	....	7.41	0.00			
Muskogee County.															
Muskogee pool, new field:															
Evans lease, Julia Oil Co., Muskogee	0.8328	97	11.0	0.7332	36.0	0.7960	52.8	0.8866	99.8	....	7.64	0.0	....	15.2	4.0
Do	0.8264	83	11.0	0.7218	36.0	0.7976	51.4	0.8855	98.4	....	6.03	0.0	....	16.8	5.0
K. Stevens lease, Success Oil and Gas Co., Muskogee	0.8314	93	12.0	0.7298	38.0	0.7984	50.3	0.8861	100.3	....	2.24	0.0	....	15.2	3.0
J. W. Siebold lease, Success Oil and Gas Co., Muskogee	0.8343	90	7.0	0.7316	40.0	0.7876	52.4	0.8861	99.4	....	1.24	0.0	....	16.8	2.0
Fort Worth Development Co. lease, of Richmond Development Co., Muskogee	0.8333	90	11.0	0.7090	37.0	0.7986	51.2	0.8861	99.2	....	1.52	0.0	....	16.4	8.0
G. W. Sadler lease, Huckleberry & Co., Muskogee	0.8348	98	5.0	0.7410	40.0	0.7828	54.6	0.8855	99.6	....	6.96	0.0	....	16.0	4.0
Prairie Oil and Gas Co., Muskogee	0.8358	99	3.5	0.7415	41.0	0.7816	55.5	0.8838	100.0	....	12.45	0.0	....	17.6	2.0
Muskogee pool, old field:															
Pioneer Oil and Gas Co., Muskogee	0.8216	110	5.5	0.7415	46.0	0.7812	43.7	0.8745	95.2	....	3.88	0.0	....	12.0	4.0
P. Connolly, Muskogee	0.8279	115	4.0	0.7520	48.0	0.7856	48.4	0.8750	100.4	....	2.15	0.0	....	11.2	2.0
Do	0.8328	140	Tr.	....	46.0	0.7810	53.2	0.8745	99.2	....	4.91	0.0	....	12.4	2.0

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM OKLAHOMA.—*Cont.*

Location of well	Specific gravity at 15°C.	Distillation by Engler's method: Begins to distil at (°C.)	By volume: To 150°C.: Cubic centimeters	To 150°C.: Specific gravity	150°–300°C.: Cubic centimeters	150°–300°C.: Specific gravity	Residuum: Cubic centimeters	Residuum: Specific gravity	Total: Cubic centimeters	Sulphur (per cent.)	Paraffin (per cent.)	Asphalt (per cent.)	Water (per cent.)	Unsaturated hydrocarbons (per cent.): Crude	Unsaturated hydrocarbons: 150°–300°C.	Remarks
Nowata County.																
Childers pool:																
Sec. 35, T. 27, R. 16, Susan Connor lease, New York and Pennsylvania Oil Co., Nowata	0.8449	80	14.0	0.7415	33.0	0.8035	51.2	0.9090	98.2	....	4.51	0.75	....	38.4	10.0	
Sec. 8, T. 26, R. 16, Jane Claggett lease, F. D. Bailey, Nowata	0.8439	78	11.0	0.7270	36.0	0.8024	51.1	0.9091	98.1	....	4.59	0.93	....	22.0	7.5	
Delaware pool:																
Sec. 31, T. 27, R. 16, Wolf lease, Davis & Berrian, Nowata	0.8493	65	16.5	0.7435	35.0	0.8195	47.4	0.9156	98.9	....	4.18	1.69	....	18.4	8.0	
Sec. 33, T. 27, R. 16, Edgar Bean lease, Van Vleck & Graham Oil Co., Nowata	0.8424	81	9.0	0.7182	38.5	0.7966	51.6	0.9138	99.1	....	8.23	1.74	....	12.8	10.0	
Delaware and Childers pools:																
Prairie Oil and Gas Co., Station 40, Nowata	0.8500	107	3.0	....	42.0	0.7918	49.8	0.9103	94.8	....	4.45	0.26	....	24.0	3.0	
Nowata and Rogers counties.																
Shallow sand pool:																
Prairie Oil and Gas Co., Station 38, Nowata	0.8537	100	7.0	0.7380	39.0	0.8034	53.8	0.9103	99.8	....	3.04	0.12	....	24.4	3.0	

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM OKLAHOMA.—*Cont.*

Okmulgee County.															
Morris pool:															
Prairie Oil and Gas Co., Morris	0.8459	112	3.0	....	34.0	0.7924	62.1	0.8866	99.1	....	11.90	0.0	....	10.0	1.0	
Meridian lease, Brown Oil and Gas Co., Morris	0.8383	82	10.0	0.7260	30.0	0.7988	57.1	0.8861	97.1	....	9.46	0.0	....	13.6	3.0	
Do	0.8403	75	13.0	0.7338	31.0	0.8008	56.4	0.8895	100.4	....	6.75	0.10	....	13.2	8.0	
Bald Hill pool:															
Buchanan lease, Burns & Caton, Morris	0.8531	110	5.5	0.7515	36.0	0.8018	58.0	0.9003	99.5	....	3.43	0.15	....	20.0	8.0	
J. W. Buchanan lease, J. Harmon, Morris	0.8578	131	1.5	....	35.5	0.8096	62.4	0.8992	99.4	....	5.70	0.76	....	16.4	3.0	
Osage County.															
Bartlesville pool:															
Prairie Oil and Gas Co., Bartlesville	0.8584	130	3.0	0.7625	39.0	0.8116	58.7	0.8980	100.7	....	5.27	0.18	....	25.2	2.0	
Lease 31, Colliver Consolidated Oil Co., Markham & Ball, Bartlesville	0.8521	115	3.0	....	43.5	0.7818	54.0	0.8992	100.5	....	2.73	1.00	....	20.4	9.0	
Do	0.8505	105	3.5	0.7499	42.0	0.7808	51.5	0.9044	97.0	....	2.61	1.34	....	30.8	12.0	
Lot 32, Illuminating Oil Co., Bartlesville	0.8547	113	3.5	0.7574	44.0	0.7868	52.4	0.9009	99.9	....	7.90	1.12	....	21.0	0.0	
Shallow sand pool:															
T. 26 N., Skelton-Moore Oil Co., Bartlesville	0.8398	76	11.5	0.7101	35.0	0.7869	51.9	0.9050	98.4	....	.....	1.26	....	21.2	8.0	
Pawnee County.															
Cleveland pool:															
Prairie Oil & Gas Co., Cleveland station	0.8485	97	10.0	0.7428	37.5	0.8074	52.5	0.8980	100.0	....	6.06	0.20	....	34.8	5.0	

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM OKLAHOMA.—*Cont.*

Location of well	Specific gravity at 15°C.	Distillation by Engler's method									Sulphur (per cent.)	Paraffin (per cent.)	Asphalt (per cent.)	Water (per cent.)	Unsaturated hydrocarbons (per cent.)		Remarks
		Begins to distil at (°C.)	By volume														
			To 150°C.		150°–300°C.		Residuum		Total								
			Cubic centimeters	Specific gravity	Cubic centimeters	Specific gravity	Cubic centimeters	Specific gravity	Cubic centimeters						Crude	150°–300°C.	
Center east side, W. ½ Sec. 20, T. 21, R. 8, Minnetonka Oil Co., Cleveland	0.8363	105	10.0	0.741	38.5	0.7923	51.1	0.8963	99.6	...	5.7	0.0	....	.....	....	Taylor sand.
Center SW. ¼ 17-21-18, Minnetonka Oil Co., Cleveland	0.8408	70	11.0	0.7345	35.0	0.8061	50.1	0.8966	96.1	...	4.5	0.0				
SW., SE. 18-21-8, Minnetonka Oil Co., Cleveland	0.8192	78	6.0	0.717	39.5	0.778	50.5	0.884	96.0	...	4.2	0.0	....	.....	....	Oswego sand.
NW. ¼ 20-21-8, Minnetonka Oil Co., Cleveland	0.8192	80	9.0	0.7145	45.0	0.784	44.2	0.896	98.2	...	6.1	0.0	....	.....	....	Skinner sand.
NW. cor. NE. ¼ 21-21-8, Minnetonka Oil Co., Cleveland	0.8197	78	8.0	0.721	43.0	0.780	47.5	0.896	98.5	...	4.2	0.0	....	.....	....	Peru sand.
SW., NW. 20-21-8, Minnetonka Oil Co., Cleveland	0.8226	105	4.0	0.7265	48.0	0.774	47.8	0.892	99.8	...	7.6	0.0	....	.....	....	Bartlesville sand.
Cleveland pool in city limits:																
Laterette lease, Test Oil Co., Cleveland	0.8516	100	9.5	0.7794	35.0	0.8166	55.4	0.8980	99.9	...	7.75	0.03	....	38.4	3.0	
Do	0.8542	115	2.5	0.7705	40.0	0.8060	55.4	0.8992	97.9	...	6.63	0.15	....	35.2	2.0	
Do	0.8516	103	7.0	0.7586	36.0	0.8124	56.4	0.8980	99.4	...	7.86	0.81	....	39.2	2.0	

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM OKLAHOMA.—*Cont.*

Ohio & Indiana Oil Co., Cleveland	0.8516	117	4.5	0.7670	39.0	0.8060	55.9	0.8980	99.4	....	6.62	0.30	....	34.8	2.0
Cleveland pool, Jordan Valley Township:															
Cory lease, F. M. Martin, Cleveland	0.8464	110	5.0	0.7530	44.0	0.7992	48.8	0.8974	97.8	....	5.55	0.05	....	32.4	3.0
L. L. Cory lease, J. E. Martin, Cleveland	0.8403	108	7.5	0.7398	44.5	0.7882	48.0	0.8974	100.0	....	5.59	1.18	....	33.2	5.0
Berger lease, Prairie Oil & Gas Co., Independence, Kan	0.8388	80	10.0	0.7200	43.5	0.7978	46.5	0.9056	100.0	....	5.42	1.12	....	38.8	7.0
Do	0.8605	120	1.0	0.7603	41.0	0.8030	56.9	0.8969	98.9	....	5.68	0.92	....	20.4	12.0
Lowery lease, Louisiana Purchase Oil Co., Cleveland	0.8459	85	15.5	0.7452	36.0	0.8119	48.5	0.9032	100.0	....	4.38	0.82	....	26.4	
Do	0.8669	140	Tr.	....	39.5	0.8139	60.7	0.9038	100.2	....	7.26	0.63	....	25.2	4.0
Rogers County.															
Alluwe pool:															
Sec. 16, T. 24, R. 17, Horace M. Adams, Chelsea	0.8413	67	10.0	0.7134	33.0	0.7910	54.2	0.9091	97.2	....	6.14	0.55	....	21.2	9.0
Do	0.8413	65	15.0	0.7245	32.0	0.7995	50.1	0.9168	97.1	....	2.89	4.01	....	23.2	9.0
Chelsea pool:															
Sec. 16, T. 24, R. 16, Steuben lease, H. M. Adams, Chelsea	0.8511	80	13.5	0.7148	31.0	0.8035	54.8	0.9168	99.3	....	9.10	1.26	....	26.0	8.0
Sec. 14, T. 24, R. 16, Bennett lease, H. M. Adams, Chelsea	0.8516	97	6.0	0.7206	35.0	0.7924	54.6	0.9272	95.6	....	4.16	2.19	....	26.4	13.0
Seminole County.															
Wewoka pool:															
Wewoka Realty & Trust Co., Wewoka	0.8844	128	1.5	....	30.0	0.8266	67.3	0.9067	98.8	....	6.28	0.90	....	30.0	3.0

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM OKLAHOMA.—*Cont.*

Location of well	Specific gravity at 15°C.	Begins to distil at (°C.)	Distillation by Engler's method							Sulphur (per cent.)	Paraffin (per cent.)	Asphalt (per cent.)	Water (per cent.)	Unsaturated hydrocarbons (per cent.)		Remarks
			By volume													
			To 150°C.		150°–300°C.		Residuum		Total							
			Cubic centimeters	Specific gravity	Cubic centimeters	Specific gravity	Cubic centimeters	Specific gravity	Cubic centimeters					Crude	150°–300°C.	
Tulsa County.																
Red Fork pool:																
J. I. Yorgee lease, Robt. Galbreath, Tulsa	0.8368	88	15.0	0.7195	36.0	0.7945	48.5	0.9073	99.5	....	2.60	0.0	....	22.4		
Do	0.8323	93	9.0	0.7220	40.5	0.7814	48.5	0.9038	98.0	....	4.39	0.0	....	17.6	1.0	
Van Yorgee lease, Robt. Galbreath, Tulsa	0.8413	90	14.0	0.7352	37.0	0.7992	48.9	0.8855	99.9	....	6.37	0.05	....	22.4	2.0	
Missouri Lincoln Trust Co. lease, L. E. Mallory & Son, Tulsa	0.8358	97	8.0	0.7268	44.5	0.7882	47.0	0.9021	99.5	....	3.92	0.35	....	14.4	3.0	
Pump station at Red Fork, Prairie Oil & Gas Co., Independence, Kans	0.8594	110	4.0	0.7430	38.0	0.7948	55.8	0.9103	97.8	....	4.88	0.15	....	18.4	1.0	
Washington County.																
Bartlesville pool:																
Prairie Oil & Gas Co., Bartlesville	0.8521	103	8.0	0.7378	37.0	0.8090	54.5	0.9038	99.5	....	3.75	0.23	....	24.4	4.0	
Dewey and north of Dewey:																
T. 27, Williams lease, Stubbs & Lowe, Dewey	0.8605	103	3.0	....	42.0	0.8008	55.0	0.9103	100.0	....	6.07	0.47	....	18.8	1.0	
Berger lease, Woodward & Roll, Dewey	0.8772	128	1.0	0.8549	32.0	0.7972	63.3	0.9024	96.3	....	3.50	1.43	....	38.0	2.0	

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM OKLAHOMA.—*Cont.*

McEwen lease, Stubbs & Lowe, Dewey......	0.8605	80	9.5	0.7299	28.0	0.7968	58.5	0.9241	96.0	....	3.68	1.26	....	34.8		
Webber pool:																
Shaler lease, Bartles Oil Co., Dewey.....	0.8368	70	13.0	0.7214	33.0	0.8008	51.9	0.9067	97.9	....	3.01	0.94	....	20.8	4.0	
Stubbs & Lowe, Dewey.	0.8485	98	6.0	0.7339	40.0	0.7928	53.9	0.9079	99.9	....	6.81	0.99	....	20.5	11.0	
(R. C. A.) Adams Oil & Gas Co., Washington, D. C........	0.8547	95	7.5	0.7559	39.0	0.8128	53.1	0.8906	99.6	....	2.26	0.85	....	30.8	14.0	

ANALYSES OF PETROLEUM FROM PENNSYLVANIA

(Not located)[1].........	0.8175	82	21.0	....	38.25	....	40.75	....	100.0							
Do[2]................	0.8014	80	21.0	0.7188	41.0	0.7984	37.00	....	99.0	0.06	....	....	....	......	1.8	Viscosity by P. R. R. pipette, 37. Crude oil: carbon, 86.10 per cent.; hydrogen, 13.90 per cent. 300°–350° C., 14 per cent.; sp. gr., 0.8338; refractive index, 1.462.
Do[3]................	[a]0.8160	......	[b]20.3	....	[c]59.7	......	......	....	100.0	....	....	....	....	....	....	[a]Sp. gr. at 0° C.; [b]up to 140° C.; [c]140°–200° C. Composition of crude oil: carbon, 82 per cent.; hydrogen, 14.8 per cent.; oxygen, 3.2 per cent. Heat of combustion, 9,963.

[1] ENGLER and LEVIN, *Dingler's polyt. J.*, **261**, 29. [2] RICHARDSON and WALLACE, *J. Soc. Chem. Ind.*, **20**, 691.
[3] BOURGOUGNON, *J. Am. Chem. Soc.*, **1**, 195.

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM PENNSYLVANIA.—*Cont.*

Location of well	Specific gravity at 15°C.	Distillation by Engler's method									Sulphur (per cent.)	Paraffin (per cent.)	Asphalt (per cent.)	Water (per cent.)	Unsaturated hydrocarbons (per cent.)		Remarks
		Begins to distil at (°C.)	By volume														
			To 150°C.		150°–300°C.		Residuum		Total								
			Cubic centimeters	Specific gravity	Cubic centimeters	Specific gravity	Cubic centimeters	Specific gravity	Cubic centimeters						Crude	150°–300°C.	
(Not located)[1]	[a]0.8861	......	......	......	[b]12.0	......	......	......	......		...	......	...	...	......	......	[a]Sp. gr., 0°C.; [b]up to 280°C. Composition of crude oil: carbon, 84.9 per cent.; hydrogen, 13.7 per cent.; oxygen, 1.4 per cent.
Do[2]	0.8160	......	19.7	......	44.77	0.792	35.52	......	99.99								
Perry County, Millerstown[3]	0.7901	......	17.0	0.693	43.0	0.765	40.0	......	100.0		...	......	...	...	......	......	Separated into 100 fractions; percentages, 43, 40, are approximate; residuum, 10 per cent.
Venango County[4]	0.8822	......	8.55	......	[a]42.78	......	[b]48.67	......	100.0		...	......	...	...	......	......	[a]150°–270°C.; [b]includes loss and water.

[1] BOURGOUGNON, *ibid.* [2] RICHARDSON, *J. Soc. Chem. Ind.*, **19**, 123. [3] BOURGOUGNON, *loc. cit.*, 204. [4] SILLIMAN, HENRY'S "History of Petroleum."

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM TEXAS

Bexar County.[1]																
San Antonio	0.8800	......	4.73	0.745	36.90	0.8117	58.37	......	100.0	2.02	....	....	....	....	....	Residue, 10 per cent.; loss, 0.30 per cent.; fraction up to 250° C., colorless.
Do	0.9179	......	1.10	......	[a]27.30	......	71.60	......	100.0	1.52	....	....	....	....	....	[a]150° – 275°C.; residue, 8.40 per cent.; loss, 2.20 per cent.
Hardin County.																
Sour Lake pool:																
Township 75, Cannon tract, O. T. Taber, Sour Lake	0.9067	95	3.0	......	31.0	0.8597	65.9	0.9440	99.9	....	0.0	0.0	Tr.	31.2	11.0	Beatty sand.
Taber Oil Co., Sour Lake	0.9272	185	......	......	20.0	0.8721	79.4	0.9409	99.4	....	0.0	0.40	Tr.	46.0	9.0	
Rodger's tract, township 81, Taber Oil Co., Sour Lake	0.9421	187	......	......	19.0	0.8761	80.4	0.9472	99.4	....	0.0	0.57	Tr.	36.4	9.0	
Graham and Gore, Sour Lake	0.9144	95	1.0	......	25.0	0.8377	72.0	0.9377	98.0	....	0.0	0.0	Tr.	31.2	11.0	
Sun Co., Beaumont	0.9352	170	......	......	23.0	0.8750	76.7	0.9569	99.7	....	0.0	0.0	....	59.6	11.0	
Minor Oil Co. (Caprock oil from Shoestring)	0.9026	96	2.0	......	32.0	0.8401	65.4	0.9409	99.4	....	0.0	0.55	....	22.8	5.0	
Sour Lake[2]	0.9630	......	[a]0.1	......	21.08	0.8282	78.82	......	100.0	....	....	20.0	....	....	....	[a]To 160°C.
Do[3]	0.9494	......	6.6	[a]0.8693	[b]15.3	0.8974	[c]78.1	......	100.0	....	....	....	....	....	....	[a]At 20°C.; [b]150° –175°C.; [c]reddish brown maltha, very sticky. Refractive indices: [a]1.474. [b]1.489, [c]1.500.

[1] *Texas Univ. Min. Survey, Bull.* **1**, 51. [2] *Am. Chem. J.*, **22**, 489; *Texas Univ. Min. Survey, Bull.* **1**, 43. [3] RICHARDSON, *J. Soc. Chem. Ind.*, **19**, 122.

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM TEXAS.—*Cont.*

Location of well	Specific gravity at 15°C.	Distillation by Engler's method									Sulphur (per cent.)	Paraffin (per cent.)	Asphalt (per cent.)	Water (per cent.)	Unsaturated hydrocarbons (per cent.)		Remarks
		Begins to distil at (°C.)	By volume														
			To 150°C.		150°-300°C.		Residuum		Total								
			Cubic centimeters	Specific gravity	Cubic centimeters	Specific gravity	Cubic centimeters	Specific gravity	Cubic centimeters						Crude	150°-300°C.	
Saratoga pool, Rio Bravo Oil Co., Houston......	0.9472	212	......	....	18.0	0.8856	81.1	0.9615	99.1	....	0.0	0.74	Tr.	66.8	9.0	
Do................	0.9217	175	......	....	28.0	0.8661	72.0	0.9504	100.0	....	0.0	0.59	Tr.	36.4	9.0	
Gulf coast oil..........	0.9272	185	......	....	20.0	0.8721	79.4	0.9409	99.4	....	0.0	0.40	....	46.0		
Batson, United Oil & Refining Co., Beaumont.[1]	0.8878	......	6.5	....	20.4	....	73.1	....	100.0	....	.....	6.0	....	......	....	14.4 per cent. solar oil; 46.7 per cent. lubricating oil.
Harris County.																
Humble pool:																
W. S. Farish, Houston (Caprock oil)........	0.9198	118	0.5	....	40.0	0.8646	58.3	0.9615	98.8	....	0.0	3.17	Tr.	26.4	5.0	
Patrick Bros., Humble; shallow well.........	0.9340	223	......	....	18.0	0.8938	81.1	0.9321	99.1	....	0.0	....	....	32.4	3.0	
Jack County.																
....	0.9211	137	0.88	....	17.53	0.8399	81.59	....	100.0	....	.....	....	....	......	....	300°C. up, 68.99 per cent.; asphalt and coke, 12.60 per cent. Special precaution against cracking. Result of redistillation of distillate also given, by which gasoline and illuminating oil product increased by cracking.

[1] *U. S. Geol. Surv., Bull.* 282 (1906).

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM TEXAS.—*Cont.*

Jefferson County.																
Beaumont[1]	0.9220									1.33						Viscosity, Redwood standard (188 seconds), 33.3 at 15.5°C.; fluid at 0°F. Carbonaceous residue on distillation to dryness, 4.40 per cent.; calorific value, B.t.u., 19,388.
Do[2]	0.9200	83								1.75				39.00		Carbon, 84.60 per cent.; hydrogen, 10.90 per cent.; oxygen and nitrogen, 2.87 per cent. Cold test, 6°F.; calorific value, B.t.u., 19,060. Carbon, 85.03 per cent.; hydrogen, 12.30 per cent.
Do[3]	0.9115		3.12		12.5		84.38		100.0							No evidence of congealing at 5°F. 4 gal. distilled: gravity of first 10-pt. samples of distillates, 38.9° Bé., 33.1°Bé., 32.6°Bé., 31.6°Bé., 30.8°Bé., 29.3°Bé., 28.6°Bé., 27.6°Bé., 26.7°Bé. Fuel oil, 78.12 per cent.

[1] *Mineral Resources of U. S.*, 1901, 571. [2] *Ibid.* [3] *Chem. Trade J.*, March 2, 1901.

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM TEXAS.—*Cont.*

Location of well	Specific gravity at 15°C.	Distillation by Engler's method									Sulphur (per cent.)	Paraffin (per cent.)	Asphalt (per cent.)	Water (per cent.)	Unsaturated hydrocarbons (per cent.)		Remarks
		Begins to distil at (°C.)	By volume														
			To 150°C.		150°–300°C.		Residuum		Total								
			Cubic centimeters	Specific gravity	Cubic centimeters	Specific gravity	Cubic centimeters	Specific gravity	Cubic centimeters						Crude	150°–300°C.	
Beaumont.—*Cont.*	0.9217	....	1.8	....	17.1	....	81.1	....	100.0	....	....	7.5	....	....	....	Solar oil, 15.4 per cent.; lubricating oil, 52.2 per cent.
Do[2]	0.9228	150	....	....	36.0	....	64.0	....	100.0	1.96	....	8.0	....	....	....	300°–350°C., 26 per cent.; 350° to asphalt, 30 per cent. Large quantities H_2S evolved, 115°–150°C.; B.t.u., 19,923.
Do[3]	0.9500	....	....	....	....	....	....	....	....	0.94	....	....	....	....	....	Distilled *in vacuo* under 13 mm. pressure; up to 150°C., 10 per cent.; sp. gr., 0.8753; 150°–230°C., 32 per cent.; sp. gr., 0.9222; 230°–300°C., 21 per cent.; sp. gr., 0.9602; above 300°C., 37 per cent. (very thick). Sulphur by Carius method.

[1] *U. S. Geol. Surv., Bull.* **282** (1906). [2] COATES and BEST, *J. Am. Chem. Soc.*, **25**, 1154. [3] MABERY and BUCK, *J. Am. Chem. Soc.*, **22**, 551.

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM TEXAS.—*Cont.*

Beaumont.—*Cont.*	0.9250	......	[a]6.0	0.851	[b]41.5	....	52.5	0.8798	100.0	2.04	.....	....	....	......	....	[a]Up to 200°C.; [b]200°–300°C.
Do[2]	0.9103	......	2.9	0.7938	39.8	....	57.3	0.8759	100.0	2.40	.....	....	....	......	....	B.t.u., 19,785. Heavy oil, 42.6 per cent.; sp. gr., 0.9078; residue, 7.6 per cent.; loss, 7 per cent. Distillates above 617°C., 36.8 per cent.; sp. gr., 0.9094.
Do[3]	0.9121	......	......	....	33.7	....	....	....	....	.....	.....	....	....	......	....	300°–360°C., 7.5 per cent.
Do[4]	0.9206	......	6.45	....	35.0	....	58.55	0.872	100.0	.....	.....	6.34	....		....	Test of kerosene: color, prime white; flash point, 120°F. Light lubricating, 21.05 per cent.; medium lubricating, 21.05 per cent.; heavy lubricating, 10.52 per cent.; loss, gas, and sulphur, 5.04 per cent.
					36.0	....	64.0	....	100.0							
Do[5]	0.9121	110	2.5	....	40.0	....	57.5	0.8749	100.0	1.75	.....	....	....	39.0	....	Ultimate composition: Carbon, 85.03 per cent.; hydrogen, 12.30 per cent.; oxygen and nitrogen, 0.92 per cent. Volatility in open dish 7 hr.), 110°C., 19.19 per cent.; 162°C., 31.31 per cent.; 205°C., 57.57 per cent.

[1] *Texas Univ. Min. Survey, Bull.* 1, 76. [2] *Ibid.*, 74. [3] *Ibid.*, 75. [4] *J. Frank. Inst.*, September, 1902. [5] *J. Soc. Chem. Ind.*, 20, 691.

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM TEXAS.—*Cont.*

Location of well	Specific gravity at 15°C.	Distillation by Engler's method: Begins to distil at (°C.)	By volume: To 150°C.		150°–300°C.		Residuum		Total	Sulphur (per cent.)	Paraffin (per cent.)	Asphalt (per cent.)	Water (per cent.)	Unsaturated hydrocarbons (per cent.)		Remarks
			Cubic centimeters	Specific gravity	Cubic centimeters	Specific gravity	Cubic centimeters	Specific gravity	Cubic centimeters					Crude	150°–300°C.	
Beaumont.—*Cont.*[1]	0.9162	......	[a]1.78	......	[b]44.08	......	54.14	......	100.0	....	....	....	....	......	......	[a]To 160°C.; [b]160°–360°C.; residue, 4.24 per cent.; loss, 5.26 per cent.
Do[2]	0.9218	......	[a]1.96	......	[b]53.77	......	44.27	......	100.0	....	....	....	....	......	......	[a]To 160°C.; [b]160°–360°C.; residue, 3.33 per cent.; loss, 3.86 per cent.
Do[3]	0.9200	......	......	......	......	......	......	......	......	2.16	....	....	....	......	......	Distilled under atmospheric pressure, 145°–200°C., 4 per cent.; 200°–250°C., 11 per cent. Distilled under 14 mm. pressure, 95°–100°C., 17 per cent.; 150°–200°C., 17 per cent.; 200°–250°C., 51 per cent.; residue, 15 per cent. Nitrogen more than 1 per cent.

[1] *Texas Univ. Min. Survey, Bull.* 1, 72. [2] *Idem.* [3] MABERY, *J. Am. Chem. Soc.*, 23, 264.

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM TEXAS.—*Cont.*

Spindletop pool:															
L. P. Hammond & Co., Chicago, Ill.	0.9085	135	0.5	......	37.0	0.8611	62.3	0.9396	99.8	....	0.0	0.0	Tr.	22.8	8.0	
Wilson-Broach Co., Beaumont	0.9126	153	....	......	33.5	0.8699	65.7	0.9434	99.2	....	0.0	0.0	....	25.2	6.0	
Marion County.															
Caddo (La.) pool, J. M. Guffey & Co., Beaumont	0.8065	100	6.0	0.7305	50.5	0.7646	42.9	0.8739	99.4	....	7.02	....	....	12.8	5.0	
Medina County.															
Dunlay[1]	0.9031	172	6.10	0.7519	29.94	0.8330	63.96	......	100.0	2.09	....	....	....	....	......	Residuum, semi-solid asphalt; 13.50 per cent. of distillate, colorless.
McLennan County.															
Waco[2]	0.8432	......	[a]1.39	......	[b]40.03	......	[c]58.58	......	100.0	....	....	....	....	....	......	[a]Up to 205°C.; [b]between 205°C. and 271°C.; [c]principally paraffin and paraffin oil.
Navarro County.															
Corsicana[3]	......	80	[a]34.6	......	[b]40.0	......	25.4	......	100.0	....	....	....	....	....	......	[a]Up to 140°C.; [b]140°-305°C. Above 305°C., 15.8 per cent.; coke residue, 9.6 per cent.

[1] *Texas Univ. Min. Survey, Bull.* 1, 52. [2] *Ibid.*, 8. [3] *Texas Agr. Exper. Sta., Bull.* 11.

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM TEXAS.—*Cont.*

Location of well	Specific gravity at 15°C.	Distillation by Engler's method									Sulphur (per cent.)	Paraffin (per cent.)	Asphalt (per cent.)	Water (per cent.)	Unsaturated hydrocarbons (per cent.)		Remarks
		Begins to distil at (°C.)	By volume														
			To 150°C.		150°–300°C.		Residuum		Total								
			Cubic centimeters	Specific gravity	Cubic centimeters	Specific gravity	Cubic centimeters	Specific gravity	Cubic centimeters						Crude	150°–300°C.	
Corsicana, *Cont.*[1]	0.8604	77	[a]24.78	0.755	[b]59.94	....	15.28	....	100.0	....	.....	....	....	.....	....	[a]Portion of fraction 77–203°F. lost before measured; [b]150°–280°C. Up to 150°, distillate colorless.
Do[2]	0.8292	54.4	[a]15.5	0.7090	[b]39.75	0.7881	44.75	....	100.0	....	.....	....	....	.....	....	[a]To 149°C.; [b]to 288°C. Distillate colorless up to 500°C.
Do[3]	0.8493	57	[a]28.0	0.7819	[b]15.8	0.8244	56.2	....	100.0	....	.....	....	....	.....	....	[a]To 151°C.; [b]151°–180°C., distilled at 25 mm. pressure. Volatile: 100°C., 10.8 per cent. naphtha; 162°C., 35.7 per cent. naphtha; 204°C., 11.2 per cent. naphtha. Cracking begins 175°C.
Do[4]	....	......	10.8	0.710	54.5	0.796	34.7	....	100.0							
Powell pool, H. G. Johnston, Corsicana; Stout lease	0.9121	168	......	....	19.5	0.8571	80.1	0.9296	99.6	....	0.0	0.0	....	31.6	5.0	

[1] *Texas Univ. Min. Survey, Bull.* **1**, 48. [2] *Ibid.*, **49**. [3] RICHARDSON, *J. Soc. Chem. Ind.*, **19**, 121. [4] THIELE, *Am. Chem. J.*, **22**, 489.

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM TEXAS.—*Cont.*

Corsicana pool, Staley & Barnsdall, Corsicana..	0.8500	138	1.0	....	46.0	0.7934	51.4	0.9056	98.4	....	3.96	0.38	Tr.	15.2	3.0
Pecos County.[1]															
Fort Stockton.........	0.9250	......	(a)	....	(b)	......	......	......	......	......	......	......	......	......	[a]To 200°C.; [b]200°–360°C. Distillate above 360° C., 27.02 per cent.; residue, 45.54 per cent., loss, 2.68 per cent.
Reeves County.															
Ross pool (near Toyah); Leatherman well......	0.9079	172	......	......	23.0	0.8449	76.7	0.9302	99.7	....	0.0	0.0	....	28.4	6.0
East of Leatherman well; Producers Oil Co., Houston........	0.8658	128	6.0	0.7710	36.0	0.8176	57.9	0.9115	99.9	....	0.0	0.0	....	18.8	6.0
Toyah[2]..............	0.9126	.....	16.0	0.7404	24.6	0.8466	60.3	....	100.0	1.00	....	....	....	....	Oil flows at 3°F.; burning point, 230°F. B.t.u., 19,440. 325°–350°C., 50 per cent. heavy oil; loss, 5.3 per cent.; residue, 14 per cent. by weight. Viscosity by Engler method, 20 at 23°C.
Travis County.[3]															
Waters Park	0.9708	.....	.....	....	58.1	0.9144	.....	.....	.....	1.26	.....	.....	.....	.....	B.t.u., 18,835. Distillation, 35 mm. pressure. Residue, ivory black, brilliant luster, sticky.

[1] *Texas Univ. Min. Survey, Bull.* 1, 53. [2] *Idem, Bull.* 9, 66. [3] *Idem, Bull.* 15.

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM UTAH

Location of well	Specific gravity at 15°C.	Distillation by Engler's method									Sulphur (per cent.)	Paraffin (per cent.)	Asphalt (per cent.)	Water (per cent.)	Unsaturated hydrocarbons (per cent.)		Remarks
		Begins to distil at (°C.)	By volume														
			To 150°C.		150°–300°C.		Residuum		Total								
			Cubic centimeters	Specific gravity	Cubic centimeters	Specific gravity	Cubic centimeters	Specific gravity	Cubic centimeters						Crude	150°–300°C.	
San Juan County.																	
....	0.8755	212	......	......	29.0	0.8283	71.5	0.9035	100.5	....	5.77	3.32	....	21.2	6.0	
Goodridge townsite, E. L. Goodridge, Goodridge	0.8363	90	10.0	0.7375	38.0	0.7967	51.6	0.8974	99.6	....	7.31	....	Tr.			
Do	0.8264	70	12.0	0.7245	36.0	0.7941	49.3	0.8974	97.3	0.26	6.09	0.80	Tr.	20.4	1.0	
Monumental Oil Co	0.8314	78	11.0	0.7235	35.0	0.7976	51.0	0.8946	97.0	0.18	5.29	0.60	....	14.8	6.0	Stray sand.
South Side Oil Co	0.8202	73	12.0	0.7130	36.0	0.7941	49.5	0.8975	97.5	0.20	3.25	0.49	....	14.4	8.0	Baby or "Goodridge" sand.
T. 42 S., R. 19 E.	0.8388	97	10.0	0.7395	37.0	0.8021	52.0	0.8986	99.0	0.40	6.79	1.11	....	19.2	6.0	Mendenhall sand.
Washington County.																	
Virgin River[1]	0.9116	.....	0.0	......	30.63	......	69.37	......	100.0	....	....	....	....	....	......	Lubricating oil, 43 per cent.; coke and loss, 26.37 per cent.
Do[2]	0.9144	.....	.....	......	......	......	......	......	100.0	1.38	....	....	....	....	......	Kerosene, 52°Bé., 8 per cent.; neutral oil, 35.3°Bé., 20 per cent.; 36.1°Bé., 40 per cent.; 33°Bé., 23 per cent. Residuum containing considerable paraffin, 9 per cent.

[1] *The Tribune*, Salt Lake City, Utah, Dec. 29, 1907. [2] *Ibid.*

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM UTAH.—*Cont.*

Virgin River[1]	0.9150	...	...	...	...	...	...	...	...	...	3.4	...	...	...	...	Kerosene, 11.8 per cent.; heavy signal oil, 9.5 per cent.; light lubricating oil, 9 per cent.; heavy lubricating oil, 55.9 per cent.; residuum, 7.7 per cent.; loss, 2.1 per cent.
Do.	0.9180	60	2.1	......	19.5	0.784	78.4	......	100.0	0.45	29.4	5.9				
Oil City[2]	0.8333	...	...	...	...	...	...	...	...	...	...	...	...	...	...	Naphtha, 70° to 250°C., 12.5 per cent., 63° Bé.; light-burning oil, 250° to 400° C., 21.2 per cent., 51° Bé.; heavy-burning oil, 400° to 500°C., 19.2 per cent., 41° Bé.; heavy oils, 500° C. up, 43 per cent., 33° Bé.
Uinta County.																
Whiskey Run (near Dragon), Tunnel Mining Co., Dragon	0.9511	250	...	...	28.0	0.9135	70.0	0.9804	98.0	...	...	...	Tr.			

[1] *Deseret Evening News*, Salt Lake City, Utah, Dec. 14, 1907. [2] H. R. ELLIS, cited in *Mineral Resources of U. S.*, 1913, ii, 1250.

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM WEST VIRGINIA

Location of well	Specific gravity at 15°C.	Distillation by Engler's method: Begins to distil at (°C.)	By volume: To 150°C.: Cubic centimeters	To 150°C.: Specific gravity	150°–300°C.: Cubic centimeters	150°–300°C.: Specific gravity	Residuum: Cubic centimeters	Residuum: Specific gravity	Total: Cubic centimeters	Sulphur (per cent.)	Paraffin (per cent.)	Asphalt (per cent.)	Water (per cent.)	Unsaturated hydrocarbons (per cent.): Crude	Unsaturated hydrocarbons (per cent.): 150°–300°C.	Remarks
Doddridge County.																
Eagles Mills; Chas. Stewart..............	0.7941	53	16.0	0.7078	40.0	0.7797	41.6	0.8679	97.6	....	5.10	0.0	0.0	10.8	5.0	Big Injun sand.
One mile south of Eagles Mills; Chas. Stewart..	0.7756	63	20.0	0.7018	38.0	0.7778	36.0	0.8552	[a]94.0	....	6.30	0.0	0.0	13.2	5.0	Big Injun sand. [a]Low because of very volatile hydrocarbons.
Sullivan pool, 1 mi. west Center Point, McElroy Creek; Laura Sweeney lease; South Penn Oil Co., Oil City, Pa......	0.7874	55	19.0	0.7146	40.0	0.7810	37.9	0.8589	96.9	...	6.02	0.0	0.0	16.0	4.0	
Morgansville pool; J. W. Allen lease; H. E. Donohue, Morgansville.....	0.8014	58	16.0	0.7162	38.0	0.7868	41.2	0.8674	95.2	....	5.19	0.0	0.0	16.8	4.0	First Cow Run sand.
Harrison County.																
Shinnston pool, Clay district; E. J. Whiteman lease; South Penn Oil Co., Oil City, Pa..	0.7977	72	14.0	0.7104	40.0	0.7777	44.1	0.8505	98.1	....	9.73	0.0	0.0	12.8	4.0	Fifty-foot sand.
Lewis County.																
About 1½ mi. southwest of Churchville; M. A. Egan lease; South Penn Oil Co., Oil City, Pa..	0.8240	120	3.5	0.7435	41.0	0.7846	55.3	0.8679	99.8	....	6.77	0.0	0.0	14.4	5.0	

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM WEST VIRGINIA.—*Cont.*

McDonald lease.......	0.8235	80	9.5	0.7260	36.0	0.7865	53.8	0.8739	99.8	....	7.10	0.0	0.0	18.8	5.0	Gants sand.
Marion County.																
....	0.8069	75	15.5	0.7065	34.0	0.7865	......	......	......	....	....	....	....	......	......	Gordon sand.
Pleasants County.																
Boydheirs' farm; Horseneck...............	0.8149	99	17.0	0.7400	35.0	0.7899	47.9	0.8642	99.9	....	6.95	0.0	0.0	4.0	4.0	Horseneck sand.
Jefferson Township; French Creek Oil Co., Marietta, Ohio.......	0.8173	140	0.7	....	48.0	0.7798	50.8	0.8573	99.5	....	7.72	0.0	0.0	6.0	1.0	Maxton sand.
Do................	0.7923	80	22.0	0.7175	36.0	0.7780	40.5	0.8560	98.5	....	4.87	0.0	0.0	7.6	3.0	Do.
McKim Township; S. Y. Ramage Oil Co., Oil City, Pa............	0.8135	119	4.0	0.7475	49.0	0.7811	46.2	0.8642	99.2	....	6.71	0.0	0.0	3.6	5.0	First Cow Run sand.
Spindle Top; Schultz Farm Oil Co., St. Marys...............	0.7896	73	18.0	0.7160	39.5	0.8003	39.7	0.8607	97.2	....	7.25	0.0	0.0	4.0	3.0	Do.
Sugar Valley; Sherlock and Toronski, Canton, Ohio...............	0.7861	92	15.0	0.7120	45.0	0.7683	38.5	0.8511	98.5	....	6.44	0.0	0.0	6.4	3.0	Big Injun sand.
Do................	0.7735	73	19.0	0.7040	45.0	0.7690	36.0	0.8492	100.0	....	5.49	0.0	0.0	6.0	4.0	First Cow Run sand.
Arvilla pool; Heneghan & Hanlan Oil Co., Sistersville..............	0.7883	123	2.0	....	68.0	0.7623	29.7	0.8413	99.7	....	3.18	0.0	0.0	4.0	4.0	Do.
Lytton pool; South Penn Oil Co., Oil City, Pa..	0.7726	68	24.5	0.7060	37.0	0.7753	34.0	0.8549	[a]95.5	....	4.87	0.0	0.0	7.6	4.0	Big Injun sand. [a]Low total because of escape of very volatile hydrocarbons.

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM WEST VIRGINIA.—*Cont.*

Location of well	Specific gravity at 15°C.	Distillation by Engler's method: Begins to distil at (°C.)	By volume: To 150°C. Cubic centimeters	To 150°C. Specific gravity	150°–300°C. Cubic centimeters	150°–300°C. Specific gravity	Residuum Cubic centimeters	Residuum Specific gravity	Total Cubic centimeters	Sulphur (per cent.)	Paraffin (per cent.)	Asphalt (per cent.)	Water (per cent.)	Unsaturated hydrocarbons (per cent.): Crude	Unsaturated hydrocarbons: 150°–300°C.	Remarks
Washington Township; Elmer Edmunds & Co., St. Marys	0.7756	53	20.0	0.6950	41.0	0.7673	35.5	0.8584	96.5	....	.....	0.0	....	......	....	Big Injun sand.
Smith Bros. & Sweeney, St. Marys	0.7883	73	15.0	0.7076	43.5	0.7688	39.4	0.8578	97.9	....	9.00	0.0				
Sweeny Bros. & Co., St. Marys	0.8005	97	14.0	0.7173	42.0	0.7700	43.4	0.8573	99.4	....	6.68	0.0	....	......	....	Keener sand.
Ohio & West Virginia Oil Co., St. Marys	0.7865	68	18.0	0.7050	39.0	0.7716	39.3	0.8587	96.3	....	7.86	0.0	....	......	....	Do.
Do	0.7865	59	20.0	0.7080	36.0	0.7744	39.1	0.8600	95.1	....	8.43	0.0	....	......	....	Do.
J. D. Dinsmoor & Co., St. Marys	0.7870	70	16.5	0.7111	41.0	0.7694	34.5	0.8573	92.0	....	5.00	0.0	....	......	....	Big Injun sand.
Ohio & West Virginia Oil Co., St. Marys	0.8041	89	18.0	0.7256	39.5	0.7818	42.8	0.8653	100.3	....	8.92	0.0	....	......	....	First Cow Run sand.
Do	0.8074	85	16.0	0.7202	37.0	0.7784	46.2	0.8663	99.2	....	5.46	0.0	....	......	....	Salt sand.
J. D. Dinsmoor & Co., St. Marys	0.8041	87	10.0	0.7220	45.0	0.7686	44.4	0.8621	99.4	....	5.56	0.0	....	......	....	First Cow Run sand.
Grant Township; N. Y. Producers' Oil Co., Belmont pool	0.7870	53	27.5	0.7093	33.0	0.7826	36.7	0.8666	97.2	....	2.45	0.0	....	......	....	Berea sands.
Jefferson Township; Dinsmoor Oil Co., St. Marys	0.7982	74	8.0	0.7165	43.5	0.7686	42.5	0.8613	94.0	....	6.93	0.0	....	......	....	First Cow Run sand.

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM WEST VIRGINIA.—*Cont.*

Ritchie County.																
Grant Township; Cairo Oil Co., Cairo; Moats (Cairo) pool	0.8895	226	......	....	11.0	0.8525	88.7	0.8906	99.7	....	4.08	....	0.0	32.8	7.0	Salt sand.
Do	0.8102	118	6.0	0.7460	46.0	0.7791	48.0	0.8547	100.0	....	6.30	0.0	0.0	6.0	3.0	Keener sand.
Grant Township; Cairo Oil Co., Cairo; Davidson (Cairo) pool	0.8102	105	7.5	0.7310	45.5	0.7781	47.2	0.8631	100.2	....	7.84	0.0	0.0	7.2	4.0	Salt sand.
Oil Ridge pool, Grant Township; R. G. Gillespie Oil Co., Pittsburgh, Pa	0.8000	87	17.0	0.7161	39.0	0.7780	43.5	0.8610	99.5	....	6.36	0.0	0.0	7.2	3.0	Do.
Elm Run pool; Bunnel Oil Co., Parkersburg	0.8000	93	10.0	0.7175	44.0	0.7717	44.9	0.8610	98.9	....	9.15	0.0	0.0	6.4	4.0	Keener sand.
Volcano pool, Grant Township; Mount Farm Oil Co., Volcano	0.8130	115	7.0	0.7360	43.0	0.7762	47.7	0.8906	97.7	....	7.17	0.0	0.0	7.6	3.0	Heavy oil sand.
Long Run field, Grant Township; Bando Oil Co., Baltimore, Md	0.8037	108	3.0	0.7370	49.0	0.7659	48.0	0.8573	100.0	....	6.92	0.0	0.0	8.0	4.0	Salt sand.
McFarlan pool, Murphy Township; Cairo Oil Co., Cairo	0.8005	90	16.0	0.7175	39.0	0.7773	45.0	0.8618	100.0	....	4.22	0.0	Tr.	8.4	2.0	Cairo salt sand.
Do	0.7705	65	22.0	0.6930	37.0	0.8076	35.2	0.8516	[a]94.2	....	5.98	....	....	6.4	3.0	Cairo salt sand. [a]Low total because of escape of very volatile hydrocarbons; average of three distillations.
Do	0.8149	130	2.5	0.7420	46.0	0.7741	51.4	0.8565	99.9	....	9.05	0.0	....	7.6	4.0	Cairo salt sand.
Cairo pool, Grant Township; Ellen Hall farm; Cairo Oil Co., Cairo	0.8154	137	1.0	....	49.0	0.7767	50.1	0.8552	100.1	....	8.16	0.0	Tr.	6.0	3.0	Big Injun sand.

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM WEST VIRGINIA.—*Cont.*

Location of well	Specific gravity at 15°C.	Distillation by Engler's method: Begins to distil at (°C.)	By volume: To 150°C.		150°–300°C.		Residuum		Total	Sulphur (per cent.)	Paraffin (per cent.)	Asphalt (per cent.)	Water (per cent.)	Unsaturated hydrocarbons (per cent.)		Remarks
			Cubic centimeters	Specific gravity	Cubic centimeters	Specific gravity	Cubic centimeters	Specific gravity	Cubic centimeters					Crude	150°–300°C.	
Cairo pool, Grant Township; Cairo Oil Co., Cairo; Biddie Deem farm	0.8051	90	10.0	0.7235	39.5	0.7761	48.1	0.8610	97.6	....	9.48	0.0	Tr.	6.4	3.0	Cairo salt sand.
Highland pool, Clay Township; Carter Oil Co., Sistersville	0.7865	79	11.0	0.7045	44.0	0.7706	41.1	0.8513	96.1	....	3.61	0.0	Tr.	6.4	4.0	Keener sand.
Whiskey Run pool, Clay Township; South Penn Oil Co., Oil City, Pa.	0.7684	[illegible]	24.0	0.7010	37.5	0.7711	34.5	0.8516	96.0	....	7.37	0.0	Tr.	8.4	4.0	Big Injun sand.
Wolf Pen pool, Grant Township; McBride Oil Co., Pittsburgh, Pa.	0.7874	92	7.0	0.7055	50.0	0.7616	40.4	0.8587	97.4	....	5.35	0.0	....	7.2	3.0	Keener sand.
Wolf Pen pool, Grant Township; Sarber Oil & Gas Co., Parkersburg	0.7804	84	13.5	0.7000	39.0	0.7638	41.8	0.8495	[a]94.3	....	5.00	0.0	(?)	8.4	4.0	Keener sand. [a]Low because of escape of very volatile hydrocarbons.
Harrisville pool, Union Township; Hartman Oil Co., Pittsburgh, Pa.	0.7839	71	20.0	0.7145	39.0	0.7763	38.3	0.8537	97.3	....	7.44	0.0	....	6.8	3.0	Squaw sand.
Harrisville pool, Union Township; Harrisville Heat & Light Co., Harrisville	0.7977	93	17.0	0.7265	42.0	0.7770	40.9	0.8485	99.9	....	5.32	0.0	....	5.6	4.0	Big Injun sand.

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM WEST VIRGINIA.—*Cont.*

Clay Township; McKelvey Oil Co., Pittsburgh, Pa.	0.7959	103	6.5	0.7300	53.0	0.7709	40.7	0.8485	100.2	....	6.52	0.0	....	5.6	4.0	Squaw sand.
Flanagan pool, Union Township; Carter Oil Co., Sistersville	0.7986	74	15.0	0.7170	41.0	0.7804	42.3	0.8647	98.3	....	6.33	0.0	....	7.2	4.0	Keener sand.
Inland pool, Union Township; South Penn Oil Co., Oil City, Pa.	0.7986	75	11.0	0.7085	38.5	0.7731	45.4	0.8618	[a]94.9	....	6.58	0.0	....	7.6	4.0	Maxton and Big Injun sand. [a]Low because of very volatile hydrocarbons.
Prunty pool, Union Township; Carter Oil Co., Sistersville	0.7701	122	3.0	0.7440	47.0	0.7771	50.5	0.8581	100.5	....	8.67	0.0	....	5.6	4.1	Big Injun sand.
Cairo pool, Grant Township; J. H. Hatfield lease; Cairo Oil Co., Cairo	0.8144	58	17.0	0.7097	36.0	0.7846	44.0	0.8615	97.0	....	7.30	0.0	Tr.	......	6.0	
Tyler County.																
J. F. Ingraham. Lot No. 1	0.8078	70	14.0	0.7163	38.0	0.7840	46.7	0.8621	98.7	....	6.11	0.0	....	12.8	5.0	Alvy-Gordon sand.
Wood County.																
Pohick pool, Williams Township; Clark & Ritchie Co., Marietta, Ohio	0.8140	97	10.0	0.7190	39.0	0.7766	50.3	0.8679	99.3	....	5.89	0.0	Tr.	11.2	3.0	Macksburg and Maxton sand.
Bras pool, Williams Township; Clark & Ritchie Co., Marietta, Ohio	0.7950	73	10.0	0.7045	42.0	0.7420	44.3	0.8658	98.3	....	6.32	0.0	Tr.	10.4	4.0	First Cow Run sand.

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM WEST VIRGINIA.—*Cont.*

Location of well	Specific gravity at 15°C.	Distillation by Engler's method: Begins to distil at (°C.)	By volume: To 150°C. Cubic centimeters	To 150°C. Specific gravity	150°–300°C. Cubic centimeters	150°–300°C. Specific gravity	Residuum Cubic centimeters	Residuum Specific gravity	Total Cubic centimeters	Sulphur (per cent.)	Paraffin (per cent.)	Asphalt (per cent.)	Water (per cent.)	Unsaturated hydrocarbons (per cent.): Crude	150°–300°C.	Remarks
Williams Township; Henderson Oil Co., Marietta, Ohio	0.8055	98	13.0	0.7245	41.0	0.7776	46.2	0.8608	100.2	....	5.33	0.0	Tr.	9.2	4.0	First Cow Run sand.
Eppelsin pool, Williams Township; Mallory Bros. and Stewart, Parkersburg	0.8111	110	3.0	0.7320	47.0	0.7721	47.1	0.8679	97.1	....	4.99	0.0	Tr.	3.6	4.0	Second Cow Run sand.
Union Township; McGinnis Oil Co., Williamstown	0.8250	131	3.0	....	44.0	0.7766	51.4	0.9265	98.4	....	5.61	0.0	Tr.	11.2	4.0	Salt sand.
Do	0.8023	70	11.5	0.7095	36.5	0.7748	47.8	0.8676	[a]95.8	....	5.90	0.0	Tr.	12.0	4.0	Second Streak Salt sand. [a]Low total because of escape of very volatile hydrocarbons; average of three distillations.
Williams Township; Consolidated Oil Co., Pittsburgh, Pa	0.8009	87	17.0	0.7205	38.0	0.7766	44.3	0.8615	99.3	....	5.69	0.0	0.0	10.4	3.0	First Cow Run sand.
Williams Township; Lydecker Tool Co., Marietta, Ohio	0.8526	170	......	....	31.0	0.7949	69.1	0.8807	100.1	....	8.84	0.0	0.0	0.0	4.0	Berea sand.

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM WEST VIRGINIA.—*Cont.*

Volcano field, Walker Township (lubricating oil); Volcanic Oil and Gas Co., Parkersburg.	0.8750	165	......	......	16.0	0.8356	82.4	0.8872	98.4	....	0.0	0.0	(a)	21.6	5.0	Heavy oil sand.
Volcano pool, Walker Township; Volcanic Oil and Gas Co., Parkersburg	0.8429	123	1.5	......	33.0	0.7954	65.8	0.8663	100.3	....	5.81	0.0	(a)	14.0	4.0	Keener sand; heavy oil sand; Big Injun sand.

(a) Much.

ANALYSES OF PETROLEUM FROM WYOMING

Norwood Spring[1]	0.8822	......	[a]5.07	0.8051	[b]75.33	0.8421	19.60	......	100.0	....	....	....	....	....	....	[a] 26°–130°C.; [b]130°–260°C.
Big Horn County.																
Bighorn basin, Greybull field, 2 miles southwest of Byron; Montana-Wyoming Oil Co......	0.8140	85	8.5	0.7446	56.0	0.8036	33.4	0.869	97.9	0.09	3.78	....	....	11.2	12.0	Colorado shale; wells close together.
SE. cor. lot 2, sec. 17, T. 52 N., R. 93 W.; bluff west of Bighorn River; Bighorn Oil & Gas Co..............	0.7821	68	14.0	0.7400	42.0	0.7706	37.0	0.8516	93.0	0.005	7.04	....	....	32.4	7.0	Sand in lower part of Colorado shale.
Do................	0.8235	......	......	......	......	......	......	......	......	....	....	....	....	....	....	Colorado shale. [a]Small quantity of oil in bailer.

[1] *Wyo. Ter. Geol. Rept.*, 1887.

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM WYOMING.—*Cont.*

Location of well	Specific gravity at 15°C.	Distillation by Engler's method: Begins to distil at (°C.)	By volume: To 150°C. Cubic centimeters	To 150°C. Specific gravity	150°–300°C. Cubic centimeters	150°–300°C. Specific gravity	Residuum Cubic centimeters	Residuum Specific gravity	Total Cubic centimeters	Sulphur (per cent.)	Paraffin (per cent.)	Asphalt (per cent.)	Water (per cent.)	Unsaturated hydrocarbons (per cent.) Crude	Unsaturated hydrocarbons (per cent.) 150°–300°C.	Remarks
Bonanza field:																
T. 49 N., R. 91 W. (Jan., 1902)[1]	0.8450	...	10.0	0.736	[a]50.0	0.8194	40.0	...	100.0	0.0149	...	...	...	...	...	13°F. added on account of altitude of Laramie, Wyo. [a]150°–310°C. 300 c.c. distilled in 10 fractions, 30 c.c. each.
T. 49 N., R. 91 W. (Sept. 24, 1902)[1]	0.8500	...	[a]10.0	0.762	[b]40.0	0.8275	50.0	...	100.0	...	...	...	...	...	...	[a]67°–164°C.; [b]164°–304.5° C. 13°F. added on account of altitude of Laramie, Wyo. 280 c.c. distilled in 10 fractions.
Sec. 13, T. 49 N., R. 91 W.[2]	0.8446	...	[a]10.0	0.736	[b]50.0	...	40.0	...	100.0	...	...	...	...	...	...	Paraffin 2 to 4 per cent. [a]80°–142°C.; [b]142°–303°C.

[1] *Wyo. Univ., Bull.* 6. [2] SLOSSON, *Wyo. Mines and Minerals,* 1904.

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM WYOMING.—*Cont.*

Cottonwood, T. 47 N., R. 90 W.[1]	0.9020	......	[a]10.0	......	[b]40.0	......	50.0	......	100.0	....	....	....	....	....	....	[a]To 164°C.; [b]164°–305.5°C.
Converse County.																
Douglas[1]	0.9610	......	......	......	[a]9.81	0.884	90.19	......	100.0	....	....	....	....	....	....	[a]179.2°–315°C. 13°F. added on account of altitude of Laramie, Wyo. 480.5 gm. distilled, which contained 30 gm. of water.
Do[1]	0.9210	......	......	......	[a]54.6	0.8689	45.4	......	100.0	....	....	....	....	....	....	Oil sand retorted and oil distilled. 13°F. added on account of altitude of Laramie, Wyo. [a]177.2°–297.2°C.
No. 203	0.8439	80	8.0	0.7205	38.5	0.7928	50.2	0.9340	96.7	....	2.0					
No. 6	0.9309	235	......	......	6.0	0.8605	82.2	0.9434	[a]88.8	....	....	....	Tr.	....	....	[a]Distillation sample included much sediment.
No. 57, 6 miles southeast of Glenrock	0.9743	225	......	......	2.0	......	97.1	0.9852	99.1	....	....	....	2.0			
Crook County.																
Belle Fourche[2]	0.9150	......	......	......	[a]22.38	0.8485	77.62	......	100.0	0.303	....	....	....	....	....	[a]Up to 297°C.; burning point, 149°C. Viscosity by Engler method, 37.7 at 20°C.; freezing point, 0°C.

[1] *Wyo. Univ., Bull.* 6. [2] *Wyo. Univ., Bull.* 3.

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM WYOMING.—*Cont.*

Location of well	Specific gravity at 15°C.	Distillation by Engler's method								Sulphur (per cent.)	Paraffin (per cent.)	Asphalt (per cent.)	Water (per cent.)	Unsaturated hydrocarbons (per cent.)		Remarks
		Begins to distil at (°C.)	By volume													
			To 150°C.		150°–300°C.		Residuum		Total							
			Cubic centimeters	Specific gravity	Cubic centimeters	Specific gravity	Cubic centimeters	Specific gravity	Cubic centimeters					Crude	150°–300°C.	
Moorcroft; Butte Crude Petroleum Co.	0.9390	......	3.0	....	40.0	....	57.0	....	100.0	....	....	....	...	......	....	(Analysis made by Von Schulz & Son, Denver, Colo.)
Fremont County.																
Lander[1]	0.8725	......	......	....	......	....	......	....	......	....	....	....	...	......	....	Sample had been weathered and had lost some of its lighter constituents. Viscosity 1.55 at 20°C., Engler method.
Do.	0.9126	120	2.0	....	23.5	0.8041	69.9	0.9543	95.4	....	0.91	4.02	...	46.4	4.0	
Do.	0.9121	93	2.0	....	21.0	0.8067	75.2	0.9589	98.2	....	1.27	5.69	...	50.8	4.0	
Do.	0.9126	105	1.5	....	24.0	0.8018	73.9	0.9605	99.4	....	0.90	11.04	...	58.0	4.0	
Do.	0.9091	108	2.5	....	23.0	0.8047	73.1	0.9589	98.6	....	0.62	15.26	...	50.8	9.0	
Do.	0.812	77	14.0	0.7244	41.0	0.7999	41.1	0.8755	96.1	....	5.85	0.0	...	10.4	5.0	
Near Dallas, T. 30 N., R. 99 W.	0.9198	93	2.5	....	22.0	....	......	....	......	....	....	....	...	50.4	....	Flask broke. Water in oil.
Do.	0.9126	120	2.0	....	23.5	0.8041	69.9	0.9543	95.4	....	0.91	4.02	...	46.4	4.0	
Do.	0.9121	93	2.0	....	21.0	0.8067	75.2	0.9589	98.2	....	1.27	5.69	...	50.8	4.0	
Do.	0.9126	105	1.5	....	24.0	0.8018	73.9	0.9605	99.4	....	0.90	11.04	...	58.0	4.0	
Do.	0.9091	108	2.5	......	23.0	0.8047	73.1	0.9589	98.6	....	0.62	15.26	...	50.8	9.0	

[1] *Idem*, 2.

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM WYOMING.—*Cont.*

Popo Agie, near Lander[1]	0.9000	95	2–5	......	30–40	0.810–0.830	......	......	......	0.66	4.0	....	....	....	....	Fire test, 58°C.; viscosity by Engler method, 13.28 at 20°C Lubricating oil sp. gr. 0.910–0.940, 35 to 40 per cent.; coke, 7 to 10 per cent.
Big Horn Basin........	0.8315	77	14.0	0.7220	45.5	0.7800	40.5	......	100.0							
Shoshone; T. 1 S., R. 1 E., W. M...........	0.8573	143	Tr.	......	51.0	0.8271	48.7	0.8929	99.7							
Do................	0.9950															
Plunkett well (near oil spring), N. ½ NE. ¼ sec. 26, T. 1 S., R. 1 E., Wind River..........	0.8121	83	13.0	0.7183	40.0	0.7943	45.9	0.8563	98.9	....	4.51	0.0	....	8.4	5.0	
Do................	0.8121	77	14.0	0.7244	41.0	0.7994	41.1	0.8755	96.1	....	5.85	0.0	....	10.4	5.0	
Shoshone Oil Co. No. 1.	0.8454	190	......	......	37.0	0.8169	59.6	0.9278	96.6	....	7.6	....	(a)	......	......	[a]Present.
Shoshone Oil Co. No. 2.	0.8335	160	......	......	48.0	0.8009	52.4	0.8696	100.4	....	8.0	0.0	0.0			
Shoshone Basin[3].......	0.9110	......	2.5	......	27.5	......	......	......	......	......	......	....	....	......	......	Lubricating oil, 52.5 per cent., sample 6.
Do[3]...............	0.9450	......	0.0	......	10.0	......	......	......	......	......	......	....	....	......	......	Lubricating oil, 72.5 per cent., sample 7.
Shoshone Field[3]........	0.9960	......	0.0	......	......	......	......	......	......	......	......	....	....	......	......	Only small quantity distilled; water in sample, so that flash-point not determined.

[1] *Mineral Resources of U. S.*, 1897. [2] REDWOOD, *J. Soc. Chem. Ind.*, 6, 408. [3] SLOSSON, *Wyo. Univ., Bull.* 2.

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM WYOMING.—*Cont.*

Location of well	Specific gravity at 15°C.	Distillation by Engler's method									Sulphur (per cent.)	Paraffin (per cent.)	Asphalt (per cent.)	Water (per cent.)	Unsaturated hydrocarbons (per cent.)		Remarks
		Begins to distil at (°C.)	By volume														
			To 150°C.		150°–300°C.		Residuum		Total								
			Cubic centimeters	Specific gravity	Cubic centimeters	Specific gravity	Cubic centimeters	Specific gravity	Cubic centimeters						Crude	150°–300°C.	
Shoshone Field[1]	......	......	0.0	......	17.0	0.807	83.0	......	100.0		...	......	...	...	......	......	Lubricating oil, sp. gr. 0.810–0.824, 21 per cent.; sp. gr 0.840–0.844, 20 per cent.; sp gr. 0.906, 27 per cent. Coke, 14 per cent.
Do[1]	0.9660	......	0.0	......	......	......	......	......	100.0		...	......	...	...	......	......	Lubricating oil, sp. gr. 0.842–0.847, 19 per cent.; sp. gr. 0.926–0.935, 45 per cent.; sp. gr. 0.957, 12.5 per cent. Coke, 14.5 per cent.; loss, 9 per cent.
Natrona County. Rattlesnake Basin[2]	0.9920	......	......	......	......	......	100.0	......	100.0		...	......	...	...	......	......	Lubricating oil, sp. gr. 0.854–0.860, 29.80 per cent.; sp. gr. 0.933, 7.40 per cent.; sp. gr. 0.950, 23 per cent. Coke, 30 per cent.

[1] *Wyo. Ter. Geol. Rept.*, 1886. [2] *Ibid.*

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM WYOMING.—*Cont.*

Salt Creek; Pa. Oil Co.[1]	0.9095	......	......	......	......	......	......	......	......	......	......	......	......	......	......	Distillations made in various ways. Viscosity at 20°C., 15.74, Engler method.
Do[2]	......	......	1.2	0.739	12.13	0.8313	86.67	......	100.0	......	......	......	......	......	......	Lubricating oil, 76.765 per cent.; coke, 3.0075 per cent.; ash, 0.148 per cent.; loss, 6.4816 per cent.
Dutch No. 1 (sample 1)	0.8221	76	8.0	0.7220	38.0	0.7881	49.3	0.8963	95.3	....	4.97	....	....	16.4	4.0	
Dutch No. 1 (sample 2)	0.8255	76	11.0	0.7210	36.0	0.7934	50.0	0.9088	97.0	....	4.91	....	....	13.2	4.0	
Dutch No. 1 (sample 3)	0.8221	66	16.0	0.7114	29.0	0.7911	52.4	0.8861	97.4	....	6.44	....	....	14.4	5.0	
Shannon No. 10	0.9097	204	......	......	12.5	0.7673	86.9	0.9192	99.4	....	1.14	....	....	15.2	6.0	
Shannon No. 12	0.9085	213	......	......	10.0	0.8673	86.6	0.9211	96.6	....	....	....	....	14.8	8.0	
Iba	0.8314	84	11.0	0.7215	34.0	0.7875	54.0	0.8923	99.0	....	5.56	....	....	13.2	4.0	
Stock	0.8563	126	1.0	......	36.0	0.7854	62.4	0.9032	99.4	....	5.63	....	....	13.2	4.0	
Powder River (Tisdale field):																
Oil Canyon	0.9180	190	......	......	14.0	0.8546	84.3	0.9302	98.3	0.38	0.0	2.31	0.19	33.2	6.0	
Salt Canyon	0.9056	......	......	......	......	......	......	......	......	0.27						
Do	0.9106	240	......	......	16.5	0.8498	80.6	0.9226	97.1	0.55	3.12	2.30	2.42	27.2	8.0	
Trail Canyon	0.9150	210	......	......	20.5	0.8541	78.7	0.9356	99.2	0.38	0.0	2.58	0.10	31.6	8.0	
Oil Mountain district[3]	......	......	......	......	[a]5.0	0.860	95.0	......	100.0	0.10	......	......	......	......	......	[a]207°–307°C. Flash, 104°C. Fractionated into 20 portions.
Uinta County.																
Spring Valley[4]	......	......	28.0	......	24.0	......	48.0	......	100.0	......	......	......	......	......	......	Signal oil, 8 per cent.; lubricating oil, 23 per cent.; paraffin, 17 per cent.

[1] *Wyo. Univ., Bull.* 1. See also TRUMBULL's "Salt Creek Oil Field, Natrona Co.," Cheyenne, 1914. [2] *Mineral Resources of U. S.*, 1894.
[3] *Wyo. Univ., Bull.* 4. [4] *U. S. Geol. Survey, Bull.*, 285 (1906).

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM WYOMING.—*Cont.*

Location of well	Specific gravity at 15°C.	Distillation by Engler's method									Sulphur (per cent.)	Paraffin (per cent.)	Asphalt (per cent.)	Water (per cent.)	Unsaturated hydrocarbons (per cent.)		Remarks
		Begins to distil at (°C.)	By volume														
			To 150°C.		150°–300°C.		Residuum		Total						Crude	150°–300°C.	
			Cubic centimeters	Specific gravity	Cubic centimeters	Specific gravity	Cubic centimeters	Specific gravity	Cubic centimeters								
Spring Valley[1]	0.8211	......	19.0	......	35.0	......	46.0	......	100.0		....	....	....	....	......	......	Lubricating oil, 42 per cent.; coke, 1.8 per cent.; loss, 2 per cent. Sample taken June 29, 1902, from car loaded Jan. 26, 1902.
Do[2]	0.8100	......	20–30	......	30–40	......	......	......	......		....	....	....	....	......	...	Paraffin, 10–20 per cent. Fraction, 77°–130°C., sp. gr. 0.723; 130°–170° C., sp. gr. 0.754; 170°–200° C., sp. gr. 0.780; 200°–259° C., sp. gr. 0.804.
Spring Valley; at 650 ft., sand[3]	0.8250	......	[a]15.0	0.740	[b]33.1	0.802	49.5	......	97.6		....	....	....	....	......	......	[a]19°–150° C.; [b]150°–255°C. 255°–317°C., 27.1 per cent.; sp. gr. 0.830; bituminous soluble, 1 per cent.; carbon and ash, 1 per cent.

[1] *Ibid.* [2] *Ibid.* [3] *Ibid.*

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM WYOMING.—*Cont.*

Spring Valley; Pittsburg-Salt Lake Oil Co.[1]	0.8100	......	21.3	0.7179	[a]39.7	0.8046	39.0	....	100.0	0.03	.....	.....	.....	....	....	[a]150°–305° C. 305°–350° C., 16.4 per cent.; paraffin, 6.2 per cent.; residue, 7.2 per cent. Oil begins to crack at 350° C.
Spring Valley[2]	0.8329	......	27.0	....	25.5	....	47.5	....	100.0	.....	.....	.....	.....	....	....	Signal oil, 7 per cent.; lubricating oil, 40.5 per cent.
Do[3]	0.8176	......	......	....	....	....	....	....	....	.....	.....	.....	.....	....	....	Sample taken at first strike, fractional distillations 10 parts: 77°–130°C., 120°–170°C., 170°–200°C., 200°–259°C. 259°–292°C., 292°–320°C., 320°–350°C., 350°–370°C., 370°–380°C., 380°–400°C. Paraffin, 10–15 per cent.
Sec. 10, T. 26 N., R. 113 W.	0.9415	90	Tr.	....	34.0	0.89	66.0	....	100.0							
Carter district[4]	0.9240	......	......	....	....	....	....	....	....	0.10	.....	.....	.....	....	....	Freezing point, 0°C. 277°–357°C., 41.9 per cent.; sp. gr. 0.866, color dark red; 357°–372° C., 38.1 per cent.; sp. gr. 0.867, color opaque.

[1] *Ibid.* [2] *Mineral Resources of U. S.*, 1902. [3] *Ibid.* [4] *Wyo. Univ., Bull.* 8.

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM WYOMING.—*Cont.*

Location of well	Specific gravity at 15°C.	Distillation by Engler's method									Sulphur (per cent.)	Paraffin (per cent.)	Asphalt (per cent.)	Water (per cent.)	Unsaturated hydrocarbons (per cent.)		Remarks
		Begins to distil at (°C.)	By volume														
			To 150°C.		150°-300°C.		Residuum		Total								
			Cubic centimeters	Specific gravity	Cubic centimeters	Specific gravity	Cubic centimeters	Specific gravity	Cubic centimeters						Crude	150°-300°C.	
Twin Creek district[1]	0.9352	......	......	......	......	......	......	......	......		0.0	......	......	......	......	......	277°-344°C., 54 per cent.; sp. gr., 0.881; flash point, 62°C.; burning point, 97°C.
Weston County.																	
Newcastle; near B. & M. Rwy.[2]	0.9230	......	......	......	......	......	......	......	......		......	......	......	......	......	......	Fractionally distilled into 10 portions: 107°-267°C., 267°-319°C., 319°-355°C., 355°-372°C., 372°-383°C., 383°-389°C., 389°-395°C., 395°-407°C. Contains paraffin.
Newcastle[3]	0.9200	......	......	......	......	......	......	......	......		......	......	......	......	......	......	Fractionally distilled into 10 portions: 107°-303°C., 303°-319°C., 319°-353°C., 353°-367°C., 367°-374°C., 374°-375°C., 375°-377°C., 377°-379°C., 379°-382°C., 382°-392°C. Contains paraffin.

[1] *Wyo. Univ., Bull.* 3. [2] *Idem*, 5. [3] *Ibid.*

TABLE XXIX (*Cont.*).—ANALYSES OF PETROLEUM FROM WYOMING.—*Cont.*

Newcastle[1]	0.9160															Fractionally distilled: 117°–277° C., 277°–327°C., 327°–353° C., 353°–367° C., 367°–375° C., 375°–382° C., 382°–394° C. Contains paraffin.
Do[1]	0.9168															Burning point, 153°C. Fractionally distilled, 20 portions; sp. gr. of first 8 fractions as follows: 0.868, 0.874, 0.881, 0.888, 0.892, 0.897, 0.897, 0.897; color, light yellow. Viscosity by Engler method at 15.5°C., 29.43.

[1] *Ibid.*

ANALYSES OF PETROLEUM FROM OTHER COUNTRIES

MEXICO.																
Vera Cruz Province.																
Topila	0.7839	155	.....	.....	98.0	0.7829	2.4	.....	100.4	(a)	Tr.	0.0	0.0	.....	.....	(a) Not determined.
NEW ZEALAND.																
Gisbourne district.																
Gisbourne	0.8642	210	.....	.....	43.0	0.7300	57.1	0.8923	100.1	....	8.88	....	(b)	16.4	7.0	Gray sandstone.
Tavanak district.																
Gisbourne	0.8495	97	10.0	0.7805	50.0	0.8281	39.9	0.8969	99.9	....	14.78	....	(b)	24.4	2.9	
PHILIPPINE ISLANDS.																
Province of Tayabos.																
East coast of Tayabos	0.8318	100	18.0	0.7698	58.0	0.8304	23.5	0.9498	99.5	....	....	....	....	15.2	9.0	(a) Below surface of well.
SPAIN.																
Province of Cadiz.																
Near Villa Martin	0.7973	87	27.5	0.7375	53.0	0.8088	18.4	0.8727	98.9	0.0	2.52	....	....	5.6	5.0	
Do	0.8018	108	19.0	0.7414	60.0	0.8000	21.0	0.8708	100.0	0.0	3.20	....	....	7.6	7.0	

(b) Some.

TABLE XXX.—COMPARISON OF REPRESENTATIVE CRUDE PETROLEUMS FROM DIFFERENT OIL FIELDS[1]

Source	Specific gravity	Distillate by volume			
		0° – 150°C.		150° – 300°C.	
		Per cent.	Sp. gr.	Per cent.	Sp. gr.
Pennsylvania	0.820	21.0	0.718	41.0	0.798
Ohio (Lima)	0.838	9.7	0.728	37.1	0.787
Illinois (Randolph County)	0.842	14.0	0.729	37.0	0.797
Kansas (Wilson County)	0.835	19.0	0.720	38.1	0.808
Oklahoma (Glenn Pool)	0.846	8.5	0.756	42.0	0.800
West Virginia	0.787	16.5	0.711	41.0	0.769
California (Coalinga)	0.915	5.7	0.771	34.1	0.858
California (Kern River)	0.961	....	.....	20.2	0.862
California (Los Angeles)	0.971	....	.....	26.3	0.885
California (Whittier Field)	0.929	4.2	0.773	38.3	0.870
Texas	0.910	2.9	0.794	39.8	0.876
Russia (Grozni)	0.869	13.4	0.730	25.6	0.808
Rumania (Bustenari)	0.842	35.4	0.734	29.8	0.840
Rumania (Campina)	0.824	37.7	0.729	30.5	0.823
Burma (Yenangyat)	0.840	17.8	.....	49.4	.....
Italy (Villeia)	0.787	55.0	.....	42.0	.....
Japan (Echigo)	0.862	21.8	.....	38.8	.....

[1] A. B. THOMPSON'S "Petroleum Mining," 1910.

CHAPTER V

THE HISTORY OF THE PETROLEUM INDUSTRY IN THE UNITED STATES

The Early History of American Petroleum.—While the petroleum industry of America is of recent origin, the crude oil was long used by the Indians.[1] The earliest mention of the occurrence of petroleum occurs in a letter dated July 18, 1627, and published in G. Sagard's "*Histoire du Canada et Voyage des Missionaires Récollets,*" 1636, which describes a visit of a Franciscan missionary, Joseph de la Roche d'Allion, to the oil springs of what is now the town of Cuba, in Allegany County, New York, and mentions that the Indian name of the place signifies "there is plenty there"[2] and that there is "a good kind of oil called Antonotons." In 1748, North America was visited by Peter Kalm, a naturalist, who, on his return, published an account of his travels,[3] together with a map on which the oil springs of Oil Creek, Pa., were indicated.

[1] Ancient oil-pit heaps, sometimes supporting trees of the growth of centuries, have been found in the vicinity of Oil Creek, Pennsylvania. The primitive methods adopted for the collection of petroleum may be briefly mentioned in this place. The earliest system undoubtedly consisted in skimming the oil from the surface of water upon which it had accumulated. It has been stated that at Paint Creek, in Johnson County, Kentucky, a Mr. George and others were in the habit of collecting oil from the sands, by making shallow canals 100 or 200 ft. long, with an upright board and a reservoir at one end, from which they obtained as much as 200 bbl. per year by stirring the sands with a pole. These so-called "stirring places" resembled similar spots at Burning Springs, in West Virginia, which were similarly worked early in the last century. Larger quantities of petroleum were obtained in remote times by the sinking of dug wells or shafts. Evidences of very old workings are to be found not only along Oil Creek, Pa., but elsewhere in America. It may be noted here that Sir Walter Raleigh published an account of the Trinidad pitch lake in 1595.

[2] See, in this connection, Peckham, "The Production, Technology, and Uses of Petroleum and Its Products," Washington, **1884.**

[3] "En resa til Norra Amerika," Stockholm, **1753–1761**. The map made by the missionaries Dollier and Galinée in 1670 (reproduced in "Histoire de la Colonie Française," Paris, **1866, 3,** 305) has marked on it "Fonteaine de bitume," near where the town of Cuba is now located. This is probably the first mention of petroleum made on a map of this country.

The statement has been made that in 1750 the Commander of Fort Du Quesne (Pittsburgh) wrote a letter describing certain religious ceremonies of the Indians wherein advantage was taken of the inflammability of crude petroleum. It is now known that this letter was fictional, and owed its origin to Judge J. Thompson and Dr. Cyrus Dickson, who conjointly published in 1830 an imaginary history of northwestern Pennsylvania in a Franklin weekly paper.[1]

David Leisberger, a Moravian missionary, who visited the Allegheny regions in 1767, made the following report: "I have seen three kinds of oil springs—such as have an outlet, such as have none, and such as rise from the bottom of the creeks. From the first, water and oil flow out together, the oil impregnating the grass and soil; in the second, it gathers on the surface of the water to the depth of the thickness of a finger; from the third it rises to the surface and flows with the current of the creek. The Indians prefer wells without an outlet. From such they first dip the oil that has accumulated; then stir the well, and when the water has settled, fill their kettles with fresh oil, which they purify by boiling. It is used medicinally, as an ointment for toothache, headache, swellings, rheumatism and sprains. Sometimes it is taken internally. It is of a brown color, and can also be used in lamps. It burns well." General Benjamin Lincoln, in a letter written in 1783 to Rev. Joseph Willard, president of the University of Cambridge, stated: "In the northern parts of Pennsylvania there is a creek called Oil Creek, which empties itself into the Allegheny River, issuing from a spring, on the top of which floats an oil, similar to what is called Barbadoes tar, and from which may be collected by one man several gallons a day. The troops in marching that way, halted at the spring, collected the oil and bathed their joints with it. This gave them great relief and freed them immediately from the rheumatic complaints with which many of them were affected. The troops drank freely of the waters—they operated as a gentle purge."

At one time, petroleum was used in America as a cure for rheumatism,[2] burns, coughs, sprains, etc., under the name of

[1] J. J. McLaurin, "Sketches in Crude Oil," Harrisburg, Pa., **1896**, 17.

[2] This use is referred to by G. H. Loskiel in his "Geschichte der Mission der Evangelischen Brüder Unter den Indianern in Nord Amerika" (1789) and in F. Cuming's "Sketches of a Tour to the Western Country" (1807). See also Scott's "Gazetter of the United States," Philadelphia, **1795**.

"Seneca oil," which was obtained near Lake Seneca, Allegany County, New York, the vicinity of which provided the earlier supplies. This oil spring was thus described in 1833 in the *American Journal of Science*[1] by Benjamin Silliman, Sr.: "The oil spring, or fountain, rises in the midst of a marshy ground; it is a muddy and dirty pool of about 18 ft. in diameter. The water is covered with a thin layer of petroleum, giving it a foul appearance, as if coated with dirty molasses, having a yellowish brown color. They collect the petroleum by skimming it like cream from a milk pan. For this purpose they use a broad flat board, made thin at one edge like a knife. It is moved flat upon and just under the surface of the water, and is soon covered by a thin coating of the petroleum, which is so thick and adhesive that it does not fall off, but is removed by scraping the instrument on the lip of a cup. It has then a very foul appearance, like very dirty tar or molasses; but it is purified by heating and straining it while hot through flannel or other woolen stuff. It is used by the people of the vicinity for sprains and rheumatism and for sores on their horses, it being in both cases rubbed upon the part. It is not monopolized by anyone, but it is carried away freely by all who care to collect it, and for this purpose the spring is frequently visited. I could not ascertain how much is annually obtained; but the quantity is considerable. It is said to rise more abundantly in hot weather than in cold. Gas is constantly escaping through the water, and appears in bubbles upon its surface."

The existence of petroleum over a considerable area in the United States was, in fact, known at a very early period.[2] There are, however, no records of the systematic collection of the oil before it was obtained in comparatively large quantities from the brine wells or springs which were worked for the production of salt. Many of these wells, which were extensively bored on the banks of the Kanawha River in West Virginia, were drilled to a great depth, and nearly all yielded petroleum and natural gas to a greater or less extent. So noticeable, in fact, was the association of oil and brine, that surface indications of the occurrence of petroleum often led to the selection of the locality for boring

[1] (1), **23**, 97.

[2] For a detailed account of the very early discoveries of petroleum, see J. D. HENRY's "History and Romance of the Petroleum Industry," 1914, **1**, 43–53.

a brine well. While the presence of the oil was invariably regarded as objectionable and often resulted in the closing of the salt works, it was collected and sold by a few as a curiosity and for medicinal use.

In 1833, S. P. Hildreth wrote as follows regarding the early use of petroleum: "From its being found in limited quantities, and its great and extensive demand, a small vial of it would sell for 40 or 50 cts. . . . In neighborhoods where it is abundant it is burned in lamps in place of spermaceti oil, affording a brilliant light, but filling the room with its own peculiar odor. By filtering it through charcoal, much of this empyreumatic smell is destroyed, and the oil greatly improved in quality and appearance. It is also well adapted to prevent friction in machinery, for, being free of gluten, so common to animal and vegetable oils, it preserves the parts to which it is applied for a long time in free motion; when a heavy vertical shaft runs in a socket, it is preferred to all or any other article. This oil rises in greater or less abundance in most of the salt wells of the Kanawha, and, collecting as it rises in the head of the water, is removed from time to time with a ladle."[1] In 1828, the use of petroleum for lighting the city of Pittsburgh was earnestly advocated; and in 1845 Lewis Peterson, Sr., of Tarentum, Pa., entered into a contract with the Hope Cotton Factory at Pittsburgh, by which he was to supply 2 bbl. of crude petroleum per week for use as a spindle lubricant in mixture with sperm oil. This mixed lubricant was used at the Hope Factory for 10 years.

A chapter (XII.) written by J. P. Hale, of Charleston, W. Va., for the volume prepared by M. F. Maury and W. M. Fontaine, and issued in 1876 by the State Centennial Board, on the "Resources and Industries of West Virginia," contains an account of the drilling of "the first rock-bored brine well, west of the Alleghenies, if not in the United States," by the brothers Ruffner, about 1806.[2] This well, referred to as "the legitimate precursor

[1] *Am. J. Sci.*, (1), **24**, 63. See also the interesting account in Charles B. Tergo's "Geography of Pennsylvania," **1843**.

[2] The work of the Ruffners may be briefly described here. In their first attempt they employed a "gum," consisting of a straight, hollow sycamore tree, about 4 ft. internal diameter; this was sunk down by cutting away the quicksand beneath, until it touched rock at a depth of 13 ft. After cutting through this, the water rose freely, but was found to contain less salt than was obtained in the upper layers of quicksand, and the hole was abandoned. They then made another attempt, about 100 yd. from the

of all the petroleum wells of the country," was bored on the bank of the "Salt Lick," or "Great Buffalo Lick," to a depth of about 58 ft., and was followed by the drilling of large numbers of wells, the Muskingum and Duck Creek Valleys soon becoming noted. To quote further from this report, "Nearly all the Kanawha salt wells have contained more or less petroleum, and some of the deepest wells a considerable flow. Many persons now think, trusting to their recollections, that some of the wells afforded as much as 25 to 50 bbl. per day. This was allowed to flow over from the top of the salt cisterns to the river, where, from its specific gravity, it spread over a large surface, and by its beautiful iridescent hues, and not very savory odor, could be traced for many miles down the stream. It was from this that the river received the nickname of 'Old Greasy,' by which it was for a long time familiarly known by Kanawha boatmen and others. At that time this oil not only had no value, but was considered a

river, but the brine obtained was still too weak, and they returned to the first "gum," which they succeeded in driving to a depth of 17 ft. By dint of careful trimming and the use of thin wedges, they succeeded in preventing the influx of water from the quicksands above the bed-rock, which they finally penetrated by the use of a spring pole, formed of a sapling 40 or 50 ft. long, fixed at an angle of about 30°, with its upper end over the well. The drilling tools, which comprised a long iron drill with a 2½-in. steel chisel-bit, were suspended from the pole; and, by pulling the end of the pole and then releasing it, the requisite motion was imparted to them. At a depth of 17 ft. in the rock, the drill penetrated a fissure, an increased flow of stronger brine resulting, but the drilling was continued, additional lengths being welded to the drill from time to time, until a sufficient supply of strong brine was obtained at a depth of 58 ft. from the surface. To raise the stronger brine without dilution by that which filtered in from above, the Ruffners constructed a long tube of two semi-cylindrical strips of wood, carefully fitting the edges and binding them together by a wrapping of twine. The tube thus formed was passed down the 2½-in. bore-hole, with a bag of wrapping at the bottom to form a tight joint below. The brine then rose through the tube into the "gum," and was removed by buckets as from an ordinary well. This simple arrangement was soon replaced by tin tubes soldered together as they were lowered, and these again were superseded by copper pipes which screwed into each other. The wrapping consisted of a piece of buckskin or calfskin sewn up like a sleeve, about 12 or 15 in. long. This was slipped over the end of the tube, and, having been securely bound at the lower end, was filled to a depth of 6 or 8 in. with flaxseed, either alone or mixed with gum tragacanth. The upper end was then bound loosely to the tube, to permit the bag to empty itself if it became necessary to withdraw the tube, and the arrangement was lowered. The seed soon swelled from the absorption of water and formed a perfectly water-tight joint.

great nuisance, and every effort was made to tube it out and get rid of it."

A well bored in 1814 to a depth of 475 ft. at Duck Creek periodically discharged from 30 to 60 gal. of oil, together with large quantities of natural gas, at intervals of from two to four days. The following description of the "American" well, bored in 1829 for brine at Little Pennox Creek, is from *Nile's Register:*[1] "Some months since, in the act of boring for salt water on the land of Lemuel Stockton, situated in the County of Cumberland, Kentucky, a vein of pure oil was struck, from which it is almost incredible what quantities of the substance issued. The discharges were by floods, at intervals of from two to five minutes, at each flow vomiting forth many barrels of pure oil. . . .

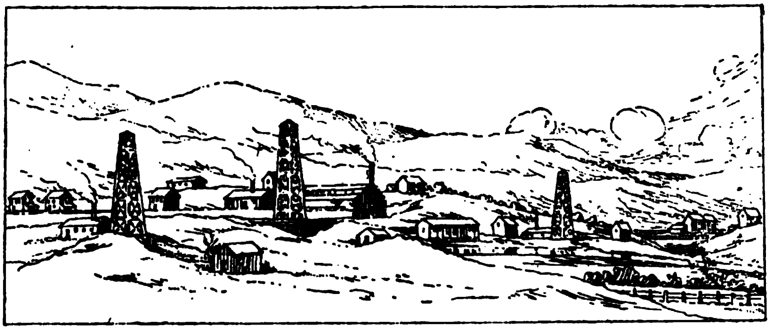


Fig. 15.—The Tarentum, Pa., brine wells, according to J. D. Henry.

These floods continued for three or four weeks, when they subsided to a constant stream, affording many thousand gallons per day." This well yielded plentifully until 1860, and the oil was sold as "The American Medicinal Oil, Burkesville, Kentucky."[2]

About 1849, S. M. Kier, a druggist of Pittsburgh, Pa., noticed the close similarity between the "American Oil" prescribed for the sickness of his wife and the petroleum obtained by his father from a brine well drilled to a depth of 500 ft.[3] at Tarentum, Pa., and commenced to bottle and retail the latter oil for medicinal use, soon effecting a sale of about 3 bbl. daily. "Kier's Petro-

[1] (3), **13**, 4.

[2] *Burkesville Courier*, Oct. 11, **1876**.

[3] The wells of Samuel and James Kier yielded about 2 bbl. of petroleum a day. On an adjoining property, the well of Irwin and Peterson produced at irregular intervals, in 1857, from 2 to 10 bbl. of oil per day.

leum" was sold at 50 cts. per half-pint bottle. Finding that the production far exceeded the sale, Kier began about 1855 to refine the oil in a roughly constructed still. The "light, wine-colored" distillate which first came over, was found useful for illuminating purposes, as "carbon oil," while the heavier product

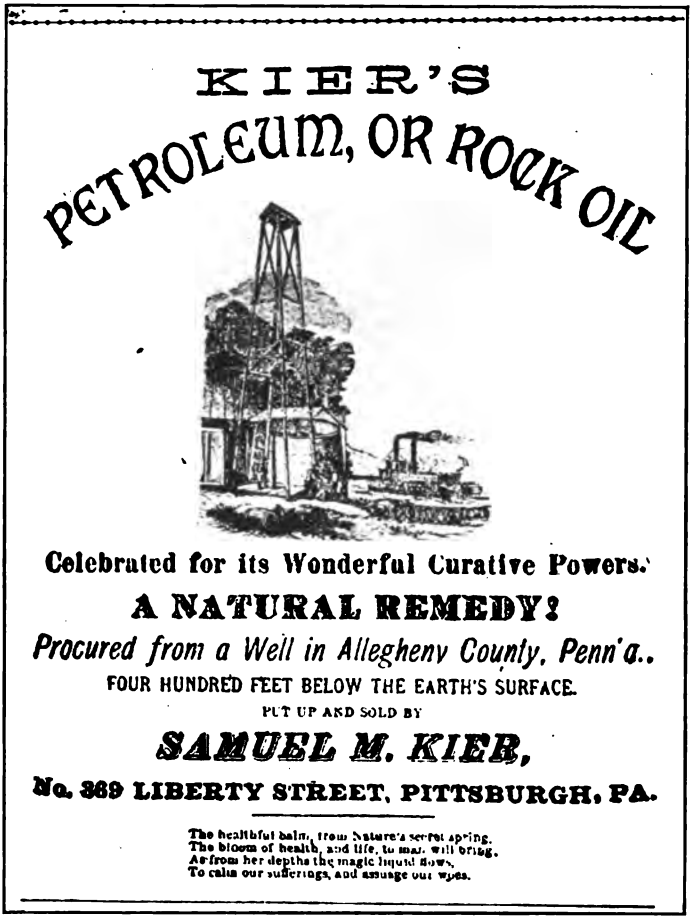


FIG. 16.—Reproduction of a circular issued by Samuel M. Kier, in 1850.

was employed at a factory in Cooperstown for cleansing wools. Kier adopted the Downer process of refining in 1860, obtaining more satisfactory results.

Petroleum vs. Oil from Coal.—Shortly after the introduction of James Young's process for obtaining paraffin and paraffin

FIG. 17.—Reproduction of a circular distributed by Samuel M. Kier, to advertise the petroleum which he marketed for medicinal purposes.

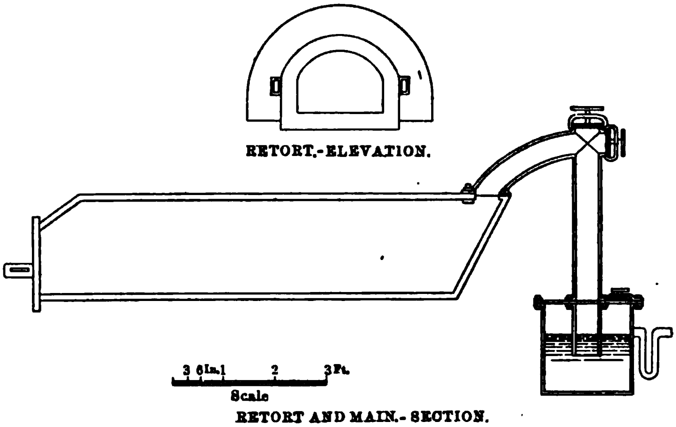


FIG. 18.—Retort employed in the distillation of bituminous coal (1860).

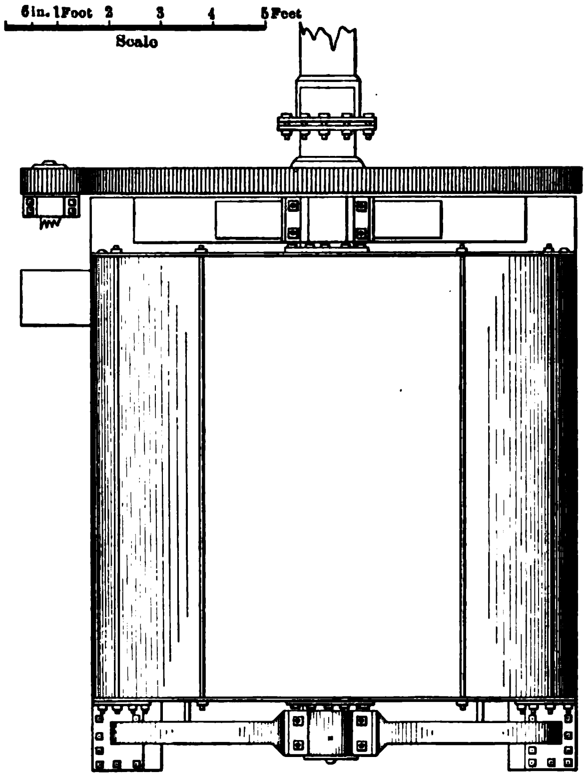


FIG. 19.—Plan of a revolving retort for the distillation of bituminous coal (1860).

oils by the distillation of coal and shale in Scotland,[1] a considerable number of "coal oil" refineries were erected in the United States.

Abraham Gesner claimed to have been the first to produce illuminating oil from bituminous materials in America; he

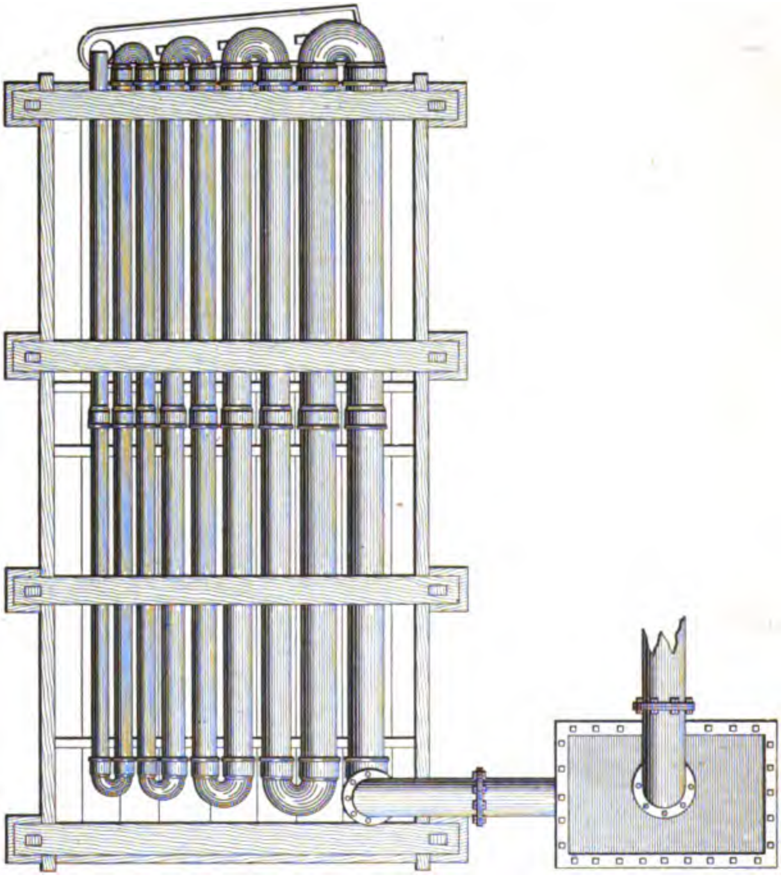


Fig. 20.—The plan of a crude oil condenser (1860).

stated[2] that at public lectures delivered in Prince Edward Island in August, 1846, he burned in lamps the oil obtained by distilling coal. Patents granted to Gesner nine years later[3] passed into

[1] See p. 809.

[2] "A Practical Treatise on Coal, Petroleum and Other Distilled Oils," 2d ed., 1865, 9.

[3] U. S. Patent 12612, Mar. 27, 1855.

the hands of the North American Kerosene Gaslight Company, which manufactured the oil at its works at Newtown Creek, Long Island, and sold it under the name of "kerosene oil."[1] Scotch "boghead" coal was distilled and a shipment was re-

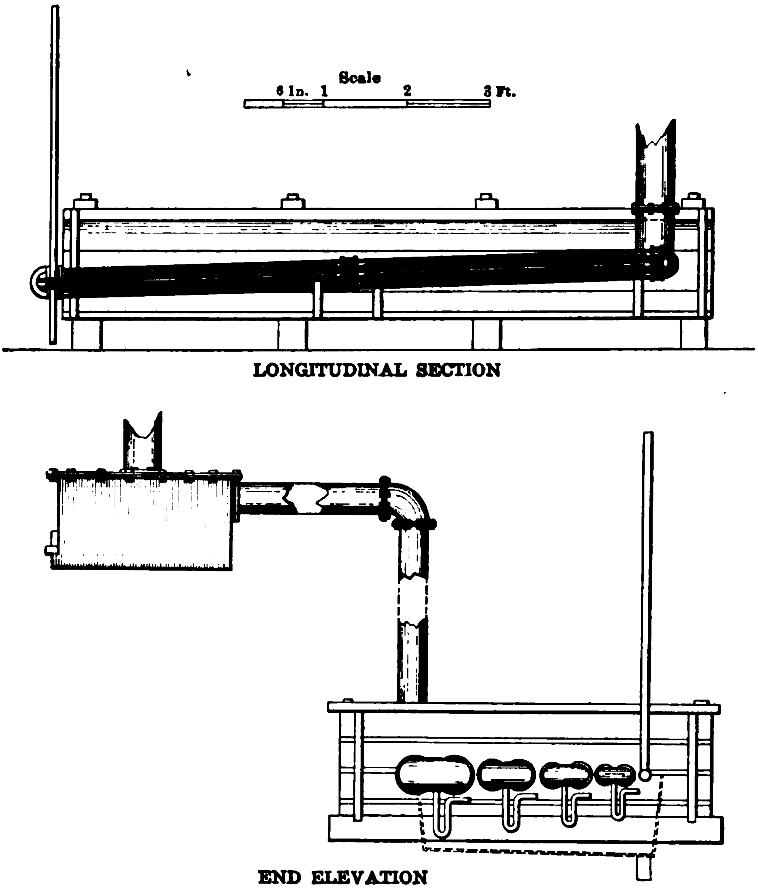


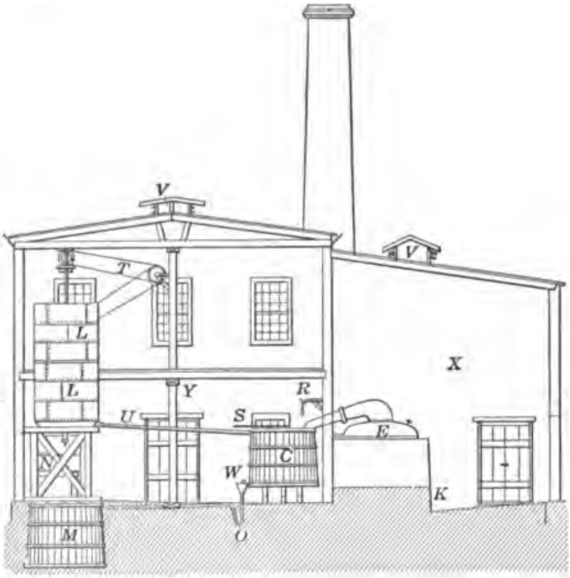
Fig. 21.—A crude oil condenser of the type in general use in the coal oil industry.

ceived monthly. The agents of this company encountered considerable difficulty in disposing of their products.

In 1853, the United States Chemical Manufacturing Company began working coal tar for the manufacture of lubricating oil

[1] The North American Kerosene Gaslight Company, which was organized in 1854, first worked under the patents of J. H. and G. W. Austin.

at Waltham, Mass., and in 1857 the Downer Kerosene Oil Company[1] first made mineral oils from albertite, mined in New



SECTION OF BROKEN LINE *A-B* OF PLAN (FIG. 23)

REFERENCES

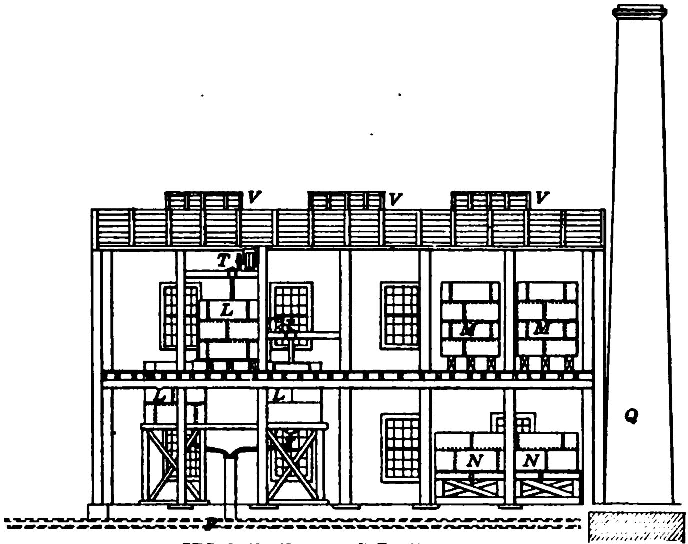
E - Stills	*P* - Drain
F - Worms	*Q* - Chimney
G - Worm Tanks	*R* - Water Pipe
H - Boiler	*S* - Steam Pipe
I - Engine	*T* - Washer Gearing
J - Steam Pump	*U* - Pipe from Agitators to Stills
K - Still Furnace	*V* - Ventilators
L - Washers, or Agitators	*W* - Tail Pipes
M - Receivers	*X* - Still House
N - Market Tank	*Y* - Refinery
O - Syphon of Still Pipe	

FIG. 22.—The plan of an 1860 coal oil refinery, having a daily capacity of 600 gallons.

Brunswick.[2] The large works of Downer in Boston were erected at a cost of half a million dollars, and at Portland, Me., Downer

[1] This Company was founded by SAMUEL L. DOWNER, of South Boston. The latter first put an oil on the market using the process of LUTHER ATWOOD, which consisted in distilling coal tar (1850). The product was sold under the name "coup oil" and was used for lubrication (CHANDLER, *J. Soc. Chem. Ind.*, **19**, 612).

[2] The lightest distillate obtained from albertite was termed "keroselene;" this was first prepared by JOSHUA MERRILL in 1857 and was used in the automatic gas machines of that day.



SECTION ON LINE *C-D* OF PLAN

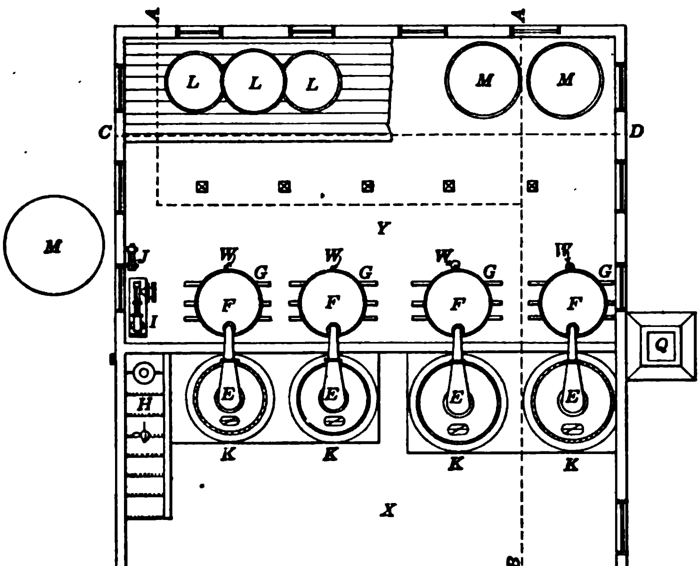


FIG. 23.—The plan of an 1860 coal oil refinery, having a daily capacity of 600 gallons.

erected a smaller works for distilling imported coal. About this time, the New Bedford Company, of New Bedford, Mass., commenced the distillation of "boghead" coal, imported from Scotland, but later substituted domestic Breckenridge coal and West Virginia coal for the imported material.

In 1859, six plants were erected by various companies near Pittsburgh, Pa., and one of these, the Lucesco Company, had a distilling capacity of 6,000 gal. of crude oil per day. This company had $120,000 invested in its works, and in 1860 ten large revolving retorts were in operation. Sixteen 2,000-gal. stills were used in the refinery. Many of the companies in operation worked under licenses from the Young Company, of Scotland. In 1860 there were 53 coal oil companies in existence in the United States; these were as follows:

Adair & Veeder, Pittsburgh, Pa.
Aladdin Company, Kiskiminetas, Pa.
Anderson Company, Darlington, Pa.
Atlantic Company, New York, N. Y.
Beloni & Co., New York, N. Y.
Boston & Portland Company, Boston, Mass.
Breckenridge Company, Cloverport, Ky.
Brooks Company, Zanesville, O.
Carbon Company, New York, N. Y.
Cornell & Co., Canfield, O.
Covington Company, Covington, Ky.
Cox Company, Zanesville, O.
Dean Company, Cleveland, O.
Downer Company, Boston, Mass.
East Cambridge Company, East Cambridge, Mass.
Empire State Company, New York, N. Y.
Enon Valley Company, Enon Valley, Pa.
Eureka Company, New York, N. Y.
Excelsior Company, New York, N. Y.
Falling Rock Company, Kanawha, Va.
Forest Hill Company, Kanawha, Va.
Franklin Company, New York, N. Y.
Glendon Company, Boston, Mass.
Grasselli Company, Cincinnati, O.
Great Kanawha Company, Kanawha, Va.
Great Western Company, Newark, O.[1]
Greers Company, Kanawha, Va.
Hartford Company, Hartford, Conn.
Himebaugh & Co., Coshocton, O.
Kerosene Oil Company, New York, N. Y.

[1] *Min. Mag.*, 9, (1857), 175.

Knickerbocker Company, New York, N. Y.
Long Island Company, New York, N. Y.
Lucesco Company, Kiskiminetas, Pa.
New Bedford Company, New Bedford, Mass.[1]
New York and Wheeling Company, Wheeling, W. Va.
New York Coal Oil Company, New Galilee, Pa.
North American Company, Kiskiminetas, Pa.
Orion Company, New York, N. Y.
Page & Co., Boston, Mass.
Palestine Company, Palestine, Pa.
Peasley Company, Boston, Mass.
Pictou Company, New York, N. Y.
Pinkham Company, Boston, Mass.
Phoenix Company, Cincinnati, O.
Preston Company, Virginia.
Ritchie Company, Ritchie County, Va.
Robinson Company, Perry County, O.
Sherwood Company, Canfield, O.
Stamford Company, Stamford, Conn.
Staunton Company, Kanawha, Va.
Union Company, Maysville, Ky.
Western Company, Monongalia County, Va.
Zephyr County, New York, N. Y.

On Mar. 4, 1858, A. C. Ferris sold the Kerosene Oil Company 9 bbl. of Tarentum petroleum for $275.19, and Luther Atwood and Joshua Merrill, then in the employ of the Kerosene Oil Company, became very enthusiastic over the results which were obtained from the distillation of this crude petroleum. On Apr. 3, 1858, Ferris made a shipment of 19 bbl. of crude oil to New York, for which he obtained $581.47; but the supply being limited, no more "carbon oil" could be supplied to the New York company. When Drake demonstrated that petroleum could be secured by drilling and that it afforded an illuminating oil superior to any that could be manufactured from coal, the "coal oil" industry became paralyzed. All that had been invested by the Kerosene Oil Company in contracts for Scotch coal and in expensive equipment became a total loss. However, many of the other coal oil refineries were converted into petroleum refineries and continued the business of manufacturing illuminating oil.

On Feb. 11, 1858, an agreement was made between MacKeown & Finley, of Pittsburgh, and A. C. Ferris & Co., of New York, by which the first party agreed to sell the second two-thirds of

[1] *Proc. Boston Soc. Nat. Hist.*, September, 1859.

their whole manufacture of "carbon oil" at 60 cts. a gallon. On July 7, 1858, A. C. Ferris & Co. contracted to take the remaining third of the Pittsburgh company, less 2 bbl. a week, at 75 cts. a gallon. The agreement was afterward extended for two years from Jan. 1, 1859.

A. C. Ferris & Co. by this time had succeeded in obtaining a good lamp for burning the new oil and were manufacturing in New York a fair quality of illuminating oil from the petroleum they secured through MacKeown & Finley from the Tarentum wells. The firm had likewise worked up a good market for the sale of their lamps and oil in the vicinity of New York. Colonel Ferris then visited Tarentum and commenced an oil shaft on the property of Irwin & Peterson at that place. This shaft was sunk to a depth of 220 ft. at an expense of $20,000. Later on Ferris purchased this entire property for $150,000 and organized the "Tarentum Oil, Salt & Coal Company." He stated that the first barrel of "carbon oil," as it was termed, was sold to Stout & Hand, grocers, at Gowanus, South Brooklyn, for 70 cts. a gallon. The early sales were generally in small quantities, together with a lamp to each invoice.

FIG. 24.—Col. A. C. Ferris.

THE DEVELOPMENT OF THE PETROLEUM INDUSTRY[1]

Having been shown some petroleum from Cherrytree Town-

[1] For reviews of the status of the petroleum industry of the United States at various times, the reader is referred to the annual volumes of *Mineral Resources of the United States* and of *Mineral Industry*, and also to the following reports: **1870**: BURKART, *Berg.-Hütt. Z.*, **29**, 373. **1872**: FAUCK, *idem*, **31**, 351. **1876**: MOSLER, "Die Petroleum-Industrie der Vereinigten Staaten von Nord-amerika im Jahr 1876," Halle, 1876; CHANDLER, *Am. Chemist*, **6**, 251. **1877**: HÖFER, "Die Petroleum Industrie Nord-amerikas in geschichtlicher, wirtschaftlicher, geologischer und technischer Hinsicht," Vienna, 1877; *Berg.-Hütt. Z.*, **36**, 16, 21. **1879**: BOLLES, "Industrial History

ship, Venango County, Pennsylvania,[1] George H. Bissell, an at-

FIG. 25.—George H. Bissell.

of the United States," Norwich, Conn., 1879. **1884**: A. N. LEET, "Petroleum Distillation," New York, 1884. **1885**: S. F. PECKHAM, "Census Report of 1880 on Petroleum and its Products." **1886**: ZINCKEN, *Oesterr. Z. Berg. Hütt.*, **34**, 51, 73, 88, 109, 125, 141, 175. **1887**: B. CREW, "Practical Treatise on Petroleum," Philadelphia, 1887. **1888**: TCHIHATCHEV, *Rev. deux Mondes*, **89**, 632; HUE, *Gorn. jurn.*, **2**, 100; STOOP, *Jaarb. Mijnw. Ned. O.-Ind.*, **17**, 5. **1894**: RICHE and ROUME, *Ann. Mines*, (9), **5**, 67; BIELIAMIN, *Izv. Obsch. Gorn. Injen.*, **1894**, Nos. 5 and 6; GULISCHAMBAROV, "The Petroleum Industry of the U.S.," Petrograd, 1894. **1895**: WM. T. BRANNT, "Petroleum and Natural Gas," Philadelphia, 1895. **1902**: SUTHERLAND, *Petrol. Rev.*, **4**, 633, 661. **1904**: ZALOZIECKI, *Naphta*, **12**, 212. **1905–1907**: PIETRUSKY, *Petroleum*, **1**, 401; **2**, 481; **3**, 630, 735; **4**, 864; **5**, 825. **1906**: WILDA, *Naphta*, **14**, 349. **1910**: BURROUGHS, *Eng. Min. J.*, **89**, 921; H. C. GEORGE, *idem*, **89**, 131; **91**, 93; **93**, 97. **1911**: LEROY-BEAULIEU, *J. Pétr.*, **11**, 36; LAZARE, *idem*, **11**, 243.

[1] The first oil lease on record is said to be the following:

"Agreed, this fourth day of July, A. D. 1853, with J. D. Angier, of Cherrytree township, in the County of Venango, Pa., that he shall repair up and keep in order the old oil spring on land in said Cherrytree township, or dig and make new springs, and the expense to be deducted out of the proceeds of the oil, and the balance, if any, to be equally divided, the

torney-at-law of New York, joined Jonathan G. Eveleth of the same city in organizing a company, which was incorporated in New York, Dec. 30, 1854, as the Pennsylvania Rock Oil Company, with a capital stock of $250,000. Some of the oil from the Cherrytree deposits was sent to Benjamin Silliman, Jr., who, in a report dated Apr. 16, 1855, addressed to Messrs. Eveleth, Bissell, and Reid,[1] gave the results which he had obtained by a study of this "rock oil or petroleum." Silliman fractionated the crude oil by distillation, and, on examining the distillates, he came to the conclusion that certain of the bodies which they contained were products of distillation and were not present in the crude oil. He studied the action of various reagents on the fractions, the behavior of the distillates when cooled,

---

one-half to J. D. Angier and the other half to Brewer, Watson & Co., for the full term of five years from this date. If profitable.

"BREWER, WATSON & CO.
"J. D. ANGIER."

Under this agreement, Angier proceeded to dig ditches and pits, and in doing so frequently struck "pockets" of oil (some of which contained a quart) in the gravel 3 or 4 ft. beneath the surface. When the ditches were first opened, from 4 to 6 gal. per day could be collected; but so much work was required to keep the oil flowing that the expenses consumed the profits, and, after a few months, the experiment was abandoned.

The deed of the first property sold for oil purposes in Pennsylvania was made by Brewer, Watson & Co., of Titusville, and conveyed to George H. Bissell and J. G. Eveleth, of New York, 105 acres of land in Cherrytree Township, Venango County, Pennsylvania. Actual consideration, $5,000 ($25,000 was mentioned in the deed). This deed was dated Nov. 10, 1854, but was not fully executed until Jan. 1, 1855.

The following copy of an early agreement is of interest:

"This Agreement, made this 11th day of October, in the year 1861, by and between Henry H. Rogers and Charles P. Ellis, of Fairhaven, Massachusetts, and Hamilton McClintock, of McClintockville, Pennsylvania.

"Witnesseth, that the said Henry H. Rogers and Charles P. Ellis, in consideration of the covenants in the part of the party of the second part to be performed, do covenant and agree to and with the said Hamilton McClintock, that they will refine and deliver to the said H. McClintock in the best manner so much good oil, together with the naphtha and waste as may be extracted from 50 barrels of crude petroleum oil by one distillation; and they furthermore agree to cooper and glaze upon the inside, paint and mark the heads of the barrels furnished by the said H. McClintock for the refined oil.

"And the said Hamilton McClintock covenants to pay to the said Henry H. Rogers and Charles P. Ellis, sixteen cents for each gallon of crude petroleum oil so refined, upon delivery, and the said H. McClintock furthermore agrees to furnish new iron-bound barrels for the refined oil and to stand his own insurance upon his oil and barrels while upon the premises of the said Henry H. Rogers and Charles P. Ellis. In witness whereof, we have hereunto set our hands and seals the day and year first above-written.

"Witness: "Henry H. Rogers.
"W. Ashbaugh. "Charles P. Ellis.
"H. McClintock."

[1] Republished in 1871 in *Am. Chemist*, **2**, 18.

the value of the different oils as illuminating agents and lubricants, and their suitability for employment as a source of gas. His report—the presentment of the results of the first systematic investigation of petroleum—gave important information on the chemistry of petroleum and determined its economic value; it is indeed a technochemical classic.

Harmony did not prevail among the members of the Pennsyl-

FIG. 26.—Benjamin Silliman, Jr., the author of technochemical classics on Pennsylvania petroleum (1855), California petroleum (1865 and 1867), and on the combustion of fuel (1860).

vania Rock Oil Company and but little was done at the Venango oil springs. Accordingly, in March, 1858, Bissell and certain other members of the Company organized the Seneca Oil Company,[1] which leased a plot of land on Oil Creek from the parent

[1] In the summer of 1856 BISSELL conceived the idea of drilling for petroleum at Titusville, Pa., and consulted with EVELETH, who favored the project. Not being so situated that they could undertake the experiment themselves, they mentioned the matter to a MR. HAVENS, of New York, who became so favorably impressed that he offered them $500 if they would secure him a lease of the property of the Pennsylvania Rock Oil Company. After

company and started operations at Titusville, Pa., for obtaining the oil by means of artesian wells. After many delays, the superintendent, E. L. Drake, engaged two drillers who had been employed in boring salt wells at Tarentum, Pa., and at the

Fig. 27.—Col. E. L. Drake.

beginning of 1859 work was commenced. Finding all attempts at digging through the surface deposits to the rock, which was

considerable delay the lease was obtained. Havens was required to pay 12 cts. per gallon for all the oil raised in 15 years, and was given one year in which to commence operations. He did not comply with the terms, and on Dec. 30, 1857, another lease was made by some of the directors, contrary to the wishes of the others, to E. E. Bowditch and E. L. Drake, at a royalty of 5½ cts. per gallon. This was soon supplemented by another restoring the royalty to 12 cts. and extending the time to 45 years. On this lease the "Seneca Oil Company" was formed Mar. 23, 1858; it had the honor of drilling the Drake well—the first "wildcat" in the Pennsylvania oil regions.

to be penetrated by the drill, to be futile on account of the caving in of the shaft, Drake successfully adopted the expedient of driving an iron tube through the quicksand and clay to the rock, a system which has since been largely employed. After drilling

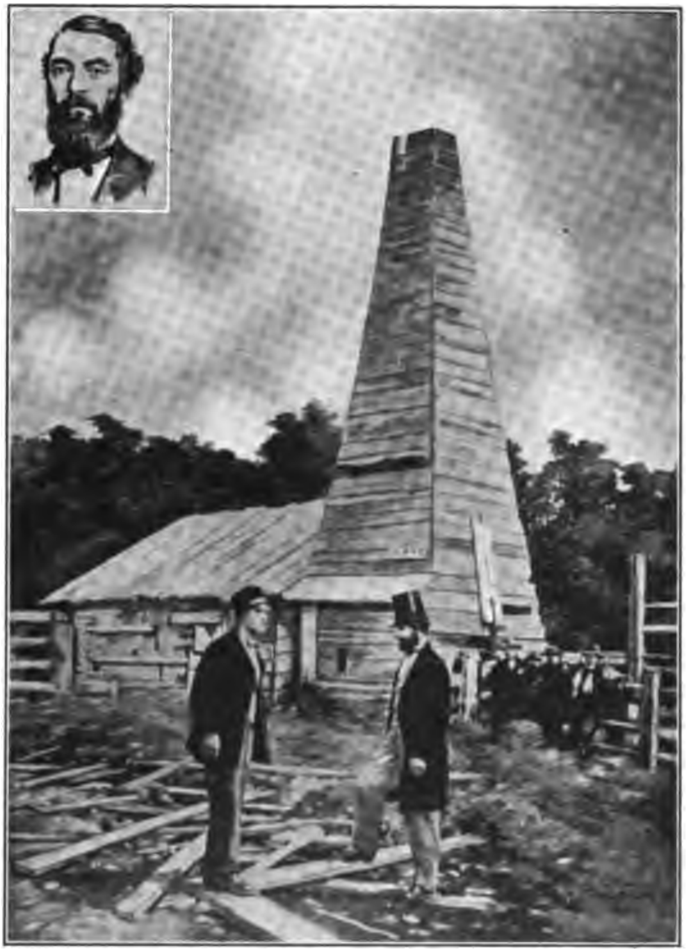


FIG. 28.—The Drake Well. Below, on the right, Drake; on the left, his driller, Smith; above (insert), Drake.

to a depth of 69 ft., the drill suddenly dropped, on Aug. 28, 1859, into a crevice, and on the following day oil was found to have been struck. At first the well yielded about 25 bbl. daily to the pump, but its production rapidly diminished, until, at

the close of the year, it did not amount to more than about 15 bbl. daily. The total yield during 1859 was under 2,000 bbl.

The success of the Drake well directly induced the rapid development of the petroleum industry. Bissell immediately

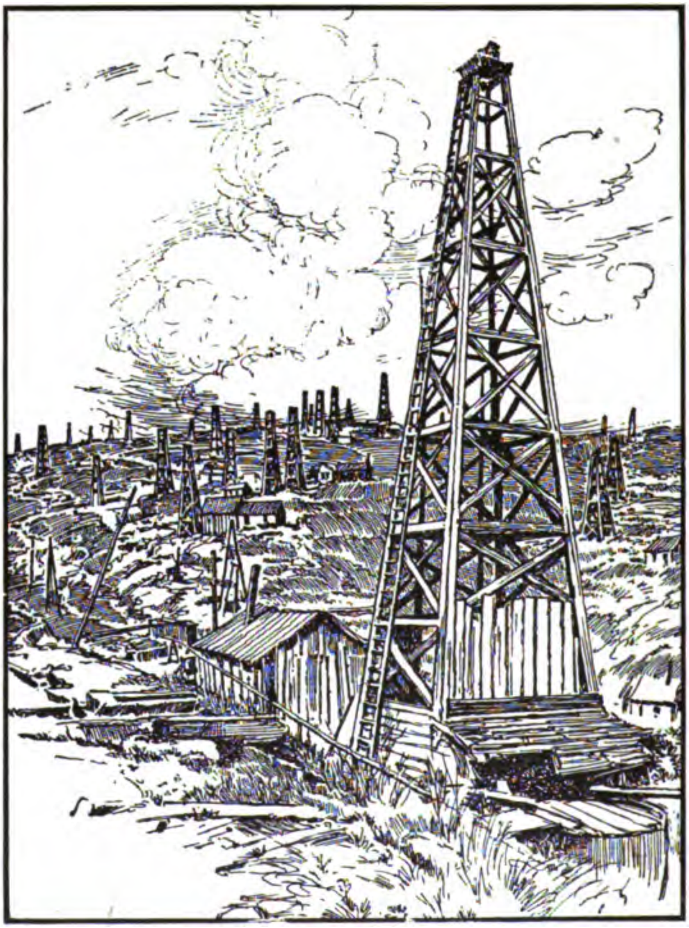


FIG. 29.—A view of Triumph Hill, near Tidioute, Pa., according to J. D. Henry.

secured all the available leases down the creek along the Allegheny River, and largely bought up the stock of the Pennsylvania Rock Oil Company. Others also secured many valuable leases, usually no rent being charged, but a royalty of one-eighth to a quarter of the oil obtained being paid by the lessees. Cone

and Johns[1] and Henry[2] have collected a large amount of interesting information on the development of the industry along Oil Creek and its vicinity. According to Cone and Johns, "Com-

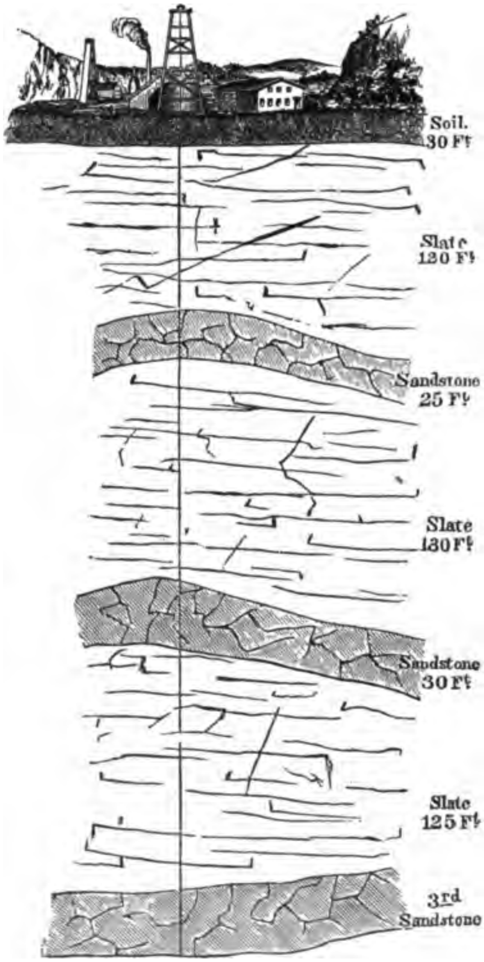


FIG. 30.—Section of a well on Oil Creek, Pennsylvania (1864).

mencing at Titusville in 1859, the tide of development swept over the valley of Oil Creek and along the Allegheny River, above and below Oil City, for a considerable distance. Cherry Run in 1864 furnished the first subsequent excitement. Then

[1] "Petrolia," N. Y., 1870.

[2] "Early and Later History of Petroleum," 1873.

came Pithole Creek, Benninghoff and Pioneer Run. The Woods and Stevenson farms on Oil Creek, near Petroleum Centre, came in like succession in 1865 and 1866. Tidioute, or rather Dennis Run and Triumph Hill, was a promising candidate for public favor in 1867, and in the latter part of the same year, Shamburgh, on Upper Cherry Run, made its brilliant début. For 1868 the Pleasantville oil field furnished the chief excitement."

In January, 1860, a pump was put into the Hamilton McClintock well, 2 miles above Oil City, and it started off at 60 gal. a minute. Operations then extended rapidly to Tidioute, Franklin, Warren and Tionesta, and a heavy oil well was struck at

Fig. 31.—A view on Oil Creek, Pennsylvania, about 1865. The scene shown was the property of the McKinley Oil Company, of New York.

Franklin.[1] Barnsdall, Meade, Abbott and Rouse struck oil near Drake's well, at a depth of 80 ft. At that depth, however, a supply of only about 5 bbl. was obtained; but in February, 1860, at a depth of 160 ft., a second supply was struck, which yielded 40 to 50 bbl. daily.[2] Most of the early wells on Oil Creek were sunk by means of the "spring pole," which was used even to a depth of 400 or 500 ft.

[1] Considerable interest was manifested in the oil business at Erie and several refineries were located there soon after the striking of the Drake well. Among the first refiners was Richard Gaggin, who began operations in 1860. In the early sixties, the upper valley of Mill Creek, near Erie, was a cluster of small petroleum refineries, among which were those of Jones and Murray, Hughes and Wright, Sloan and Douglass, and Hammond and Wilkins.

[2] From this well, between Feb. 1 and June 1, 1860, 56,000 gal. of petroleum were sold for $16,800. The total cost of drilling, etc., was $3,000.

It is worthy of mention that, during the early days of the petroleum industry in America, drilling was carried on in quite an unsystematic manner, without regard to any geological or other features of the country, except such delusive indications as were furnished by superficial outflows of oil, the rising of gas and oil in wells drilled for water or brine, or the appearance of exudations of oil and semi-solid bitumen. The number of wells drilled was frequently far in excess of the number which should have been sunk. This was especially the case along Oil Creek, where leases of only a quarter of an acre were often worked upon, thus ensuring the sinking of about twenty times as many wells as there should have been.

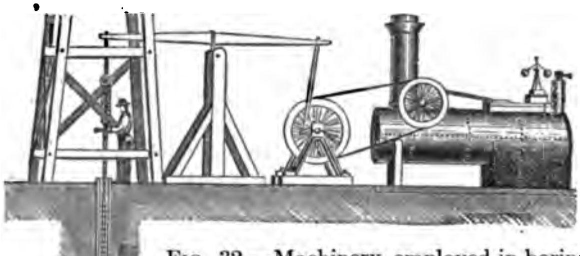


FIG. 32.—Machinery employed in boring petroleum wells, in use about 1865.

The appearance of gas and oil in the brine wells at Tarentum, Pa., and elsewhere, and the subsequent drilling of wells for the express purpose of obtaining petroleum, were the most potent factors in the early development of the industry in America; and the successive boring of neighboring wells, together with the energy displayed by the speculative "wildcat" prospectors, who drilled wells in untested territory, and in many cases regardless of any oil indications whatever, soon led to the mapping out of a large area of producing country in Pennsylvania and New York. The drillers in Venango County quickly ascertained that petroleum was contained in a series of sandstones embedded in shale; and three of these deposits, respectively termed the first, second, and third sands, and all included under the general name of oil-sands, were recognized.

The first "flowing well" in the oil regions of Pennsylvania, was obtained in the summer of 1860 on the Buchanan farm, near

Rouseville; it was called the "Curtis well" and was a little less than 200 ft. deep.

On Apr. 12, 1861, Kincaid and Co. struck a 10-bbl. flowing well on the Clapp farm, and two days later Shearer and Co. got a 20-bbl. flowing well on the same farm at a depth of 165 ft.

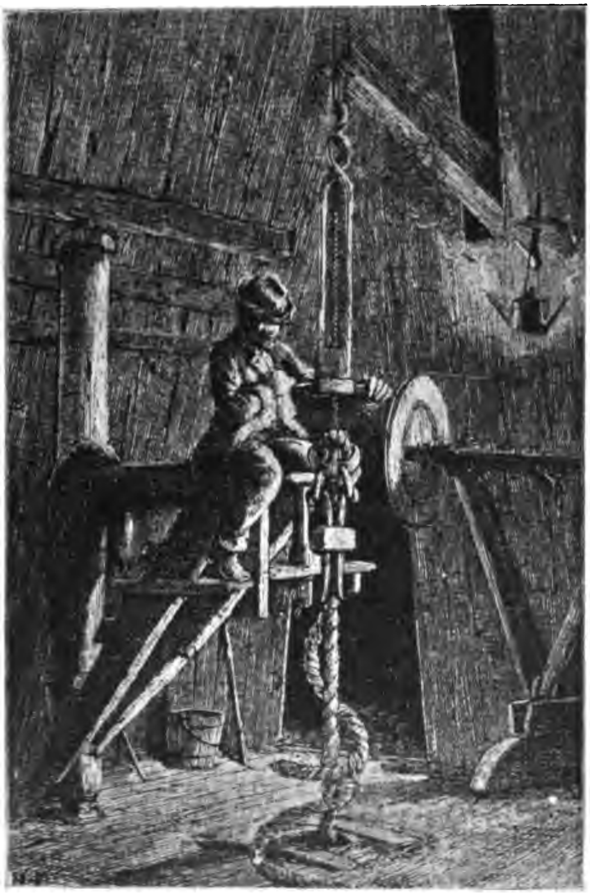


FIG. 33.—Inside view of an early derrick.

The "Fountain well," which was sunk on the Upper McElhenny or Funk farm, produced 300 bbl. daily for six months, and then stopped short, having, it was said, become choked by the solidification of paraffin. The Empire well, drilled to the same depth on the same farm, was completed in September, 1861. It

commenced to flow at the rate of 2,500 bbl. daily, and six weeks afterward its regular daily product amounted to 2,200 bbl.; but in May, 1862, the flow suddenly ceased. The well was ultimately cleaned out and yielded 300 bbl. daily to the pump for about nine months.

The Lower McElhenny farm gave, among others, the "Davis & Wheelock well," flowing at the rate of 1,500 bbl. daily, and the Densmore wells, Nos. 1, 2, and 3, which daily yielded 600, 400, and 500 bbl., respectively.

The "Maple Shade well," struck on Aug. 5, 1863, on the Hyde & Egbert farm at Petroleum Centre, started off at 1,000 bbl.

FIG. 34.—A view of the McClintock or "Coal Oil Johnny" Steele farm, perhaps the most famous oil property of Pennsylvania. The insert is a picture of Steele.

daily, and is said to have given $1,500,000 profit to its owners. The J. W. McClintock farm, afterward covered by the city of Petroleum Centre, consisted of 207 acres, and was the site of not less than 150 wells, nearly 80 per cent. of which was remunerative.

At a depth of 491 ft., the Phillips No. 2 well, on the Tarr farm, was struck in September, 1861. It gave a stream of 4,000 bbl. daily, the yield being maintained at nearly that amount for months. The well, which is estimated to have yielded 750,000 to 1,000,000 bbl., flowed for a year, and was then pumped. It produced largely for 12 years, but was finally shut down in 1873.

The Woodford well, a few rods from the Phillips, yielded 3,000 bbl. daily in December, 1861, and was found to be connected with that well, for, when either ceased working, only water could be obtained from the other.

On the Farrel farm was the Noble & Delamater well, which flowed at the rate of 3,000 bbl. daily. It was sunk in January, 1863, and continued to yield until 1865, having, it is estimated, produced $3,000,000 worth of oil. The Sherman well, on the Foster farm, Oil Creek, commenced at the rate of 1,000 bbl. on Mar. 18, 1862; it is said to have yielded 900 bbl. daily for two years.

The excitement at Pithole commenced on Jan. 8, 1865, when

FIG. 35.—The Phillips and Woodford wells on the Tarr farm.

the celebrated United States or Fraser well was struck on the Thomas Holmden farm in a ravine on Pit Creek. This well, the property of the United States Oil Company, produced at the rate of 250 bbl. daily and oil was sold at $8 a barrel; but the yield gradually diminished and ceased in November of the same year. On the same farm were the Twin wells (800 bbl. daily), the No. 54 well (800 bbl.), the Grant well (450 bbl.), and the Eureka well (800 bbl.; total production during life, 50,000 bbl.). Other flowing wells were struck on the adjoining Rooker farm, and on the adjacent Hyner and Copeland farms; but, although all gave excellent results at the commencement (the Holmden farm producing from 3,000 to 4,000 bbl. when at its best), none of the wells yielded for more than a few months. Pithole City was

a typical "oil country" city.[1] Built up in an incredibly short time, it had a population estimated at 14,000 before the end of September, 1865, and its post office ranked next in importance in the State to those of Philadelphia and Pittsburgh. As, however, its production fell off, its prosperity rapidly declined, and within two years of its foundation it was practically deserted. Throughout the "oil country," as the producing fields changed, the population shifted with the fields, and the towns that had sprung from the wilderness vanished almost as quickly as they had grown.

Borings in the valley of the Muskingum, in Ohio, and on the little Kanawha were also attended with success. The development of the Mecca field in Trumbull County, Ohio, dates from

FIG. 36.—The "Red Hot" field, known primarily as the Twombley Tract, which first yielded petroleum in 1869. This field was the scene of the operations of the firm of Winsor Brothers. (J. D. Henry.)

1860, when boring operations were started on a large scale. Several thousands of barrels were taken out yearly for some time, but the greater number of the wells, which were very shallow, rarely exceeding 100 ft. in depth, were soon abandoned, and subsequent operations did not result in any large increase. In 1860, an old brine well at Burning Springs, West Virginia, was reopened and yielded about 50 bbl. of oil daily; and the following year the Llewellyn well, with a depth of only 100 ft., flowed over 1,000 bbl. daily, and subsequently at the rate of 1,400 to 2,000 bbl. daily for some months. Oil was also obtained in 1860 and 1861 at Oil Springs, on the Hughes River. The occurrence of petroleum in brine wells in Washington County, Ohio, is referred to by Hildreth,[2] and several wells were drilled from 1860 to 1865 at Cowrun and elsewhere in that district.

[1] "The History of Pithole" was prepared by C. C. LEONARD in 1867.
[2] *Am. J. Sci.*, **24** (1833), 63; **29** (1836), 87.

Fig. 37.—William H. Abbott, a pioneer of the Pennsylvania oil fields.

Fig. 38.—C. D. Angle, a large producer of petroleum in the early development of the Pennsylvania fields.

Fig. 39.—B. A. Funk, who played a prominent part in the early development of the Pennsylvania petroleum industry.

FIG. 40.—Hamilton McClintock, one of the most prominent of the early oil operators of Pennsylvania. Mr. McClintock was born on January 19, 1820, and died on July 29, 1882.

FIG. 41.—Orange Noble, a well-known operator in the early Pennsylvania oil fields.

Although wells had been drilled near the junction of the Clarion and Allegheny rivers as early as 1863, the development of the "lower country" lying in Butler, Armstrong, and Clarion counties, Pennsylvania, did not commence until 1868.

The following statement shows approximately the early growth of the American petroleum industry: In 1859, the total production, which was wholly obtained from Oil Creek, amounted

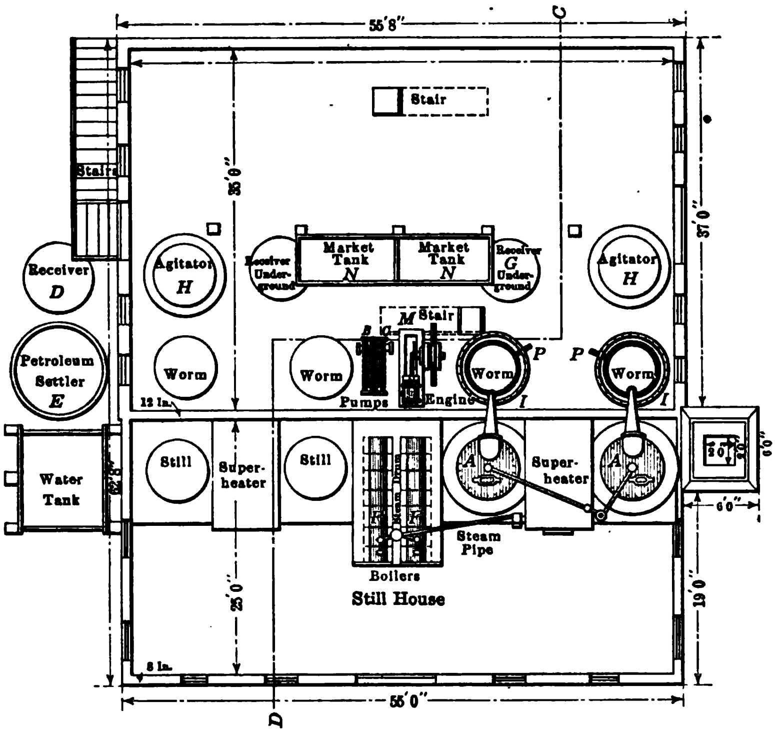
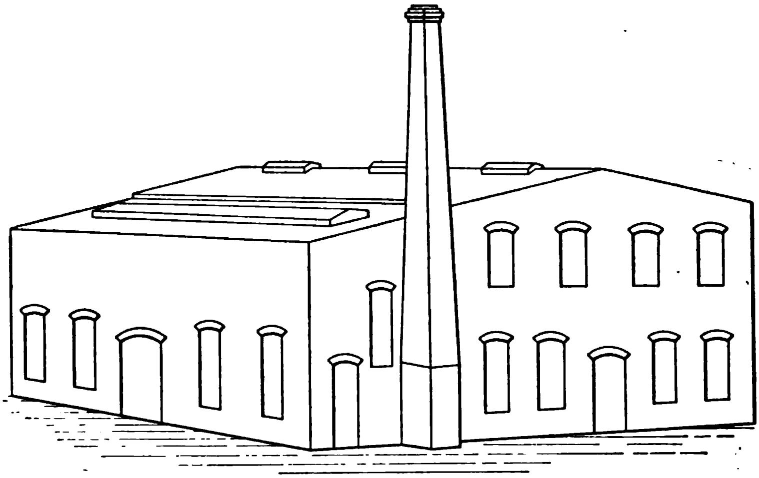
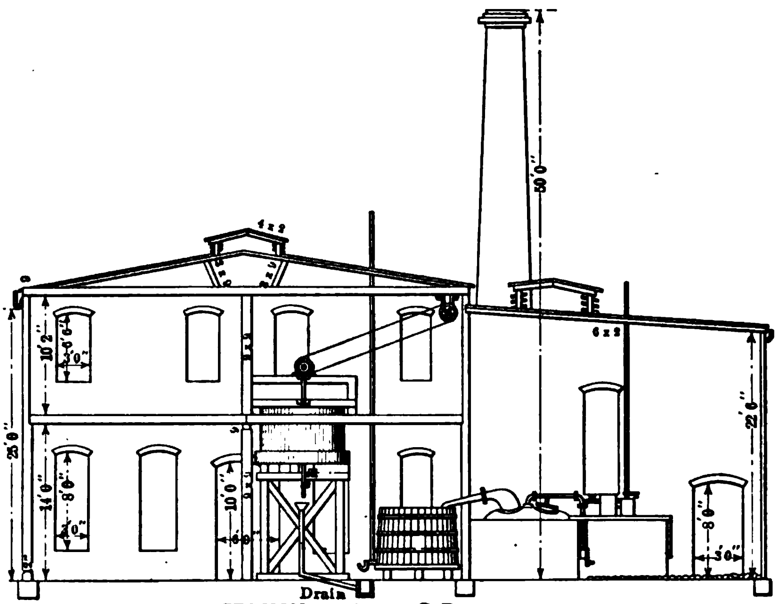


FIG. 42.—A plan of the type of petroleum refinery erected in the early sixties.

to about 2,000 bbl. In June, 1860, the wells along Oil Creek yielded about 200 bbl. daily, and in September, 1860, about 700. The yield then rapidly increased, owing to the discovery of flowing wells, until, during the winter and spring of 1861 to 1862, it amounted to about 15,000 bbl. daily. The price obtained for the oil then fell so low that production was largely arrested, until, according to Cone and Johns, "the production of 1863 was scarcely half that of the beginning of 1862, and



ELEVATION



SECTION ON LINE *C-D* OF FIG. 42

FIG. 43.—A plan of the type of petroleum refinery erected in the early sixties.

that of 1864 still less. In May, 1865, the production had declined to less than 4,000 bbl. a day, the valley of Oil Creek being the only producing locality at that time." It is estimated that some ten million bbl. of petroleum ran to waste in Pennsylvania prior to and in 1862, owing to the absence of a market therefor.

The *Oil City Register* for June, 1, 1862, gives the following estimates for the Oil Creek valley at that date: Daily production, 5,717 bbl.; flowing wells, 75; wells sunk and in process of being drilled, 358; amount of oil in hand, 92,450 bbl.; total production prior to May, 1862, 1,000,000 bbl.; cost of sinking wells, $495,000; cost of machinery, buildings, tanks, etc., $500,000; total number

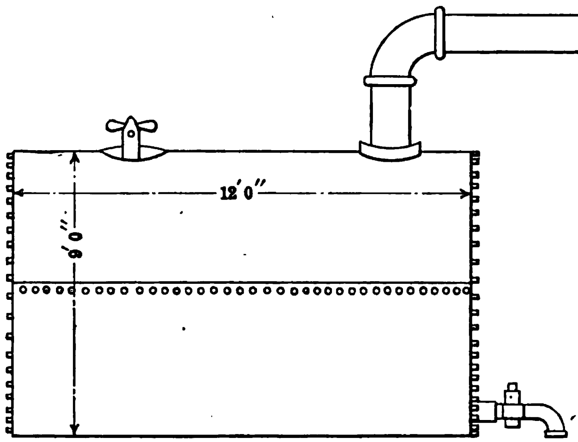


FIG. 44.—A petroleum still of the type in use in the early sixties.

of refineries, 25. In 1865, a refinery capable of handling 2,000 gal. of crude petroleum per day cost about $11,230.

After the middle of the year 1864, the petroleum industry began to expand, and the production has since steadily increased. For some years the Pennsylvania fields remained the principal source of supply,[1] but a small quantity of petroleum soon began

[1] For further information regarding the history of the oil regions of Pennsylvania, the following literature should be consulted:

BONE'S "Petroleum and Petroleum Wells. Guide-book and Description of the Oil Regions of Pennsylvania, West Virginia, and Ohio," Philadelphia, **1865**; BUCK'S "Early History of Pennsylvania," **1876**; CARLL'S "The Oil and Gas Region," *Ann. Rept. Geol. Survey Pa.*, **1886**, 575–786; CONE and JOHNS' "Petrolia. A Brief History of the Pennsylvania Petroleum Region, its Development, Growth, Resources, etc., from 1859 to 1869," New York, **1870**; GILLELEN'S "The Oil Regions of Pennsylvania," Pittsburgh, **1864**;

to be produced in the states of Ohio,[1] West Virginia,[2] Kentucky,[3]

Harris' "History of the Venango Oil Regions," Titusville, Pa., **1866**; Ridgway's "Report on the Oil District of Oil Creek in the State of Pennsylvania," *J. Frank. Inst.*, **45** (1863), 269–73; and Wright's "The Oil Regions of Pennsylvania," New York, **1865**. The chronology of the Pennsylvania oil regions is given in detail in "The Derrick's Hand-book of Petroleum," Oil City, Pa., **1898, 1**, 18 *et seq.*

The following table gives the range of the market for Pennsylvania petroleum, 1860 to 1913:

Year	Highest	Lowest	Year	Highest	Lowest	Year	Highest	Lowest
1860	$20.00	$2.00	1878	$1.87½	$0.78¾	1896	$1.50	$0.90
1861	1.75	0.10	1879	1.28¾	0.63⅛	1897	0.96	0.65
1862	2.00	0.10	1880	1.24⅜	0.71¼	1898	1.19	0.65
1863	4.00	2.00	1881	1.01¼	0.72½	1899	1.66	1.13
1864	14.00	3.75	1882	1.35	0.49¼	1900	1.68	1.05
1865	10.00	4.00	1883	1.24¾	0.83¼	1901	1.30	1.05
1866	5.00	1.65	1884	1.15⅝	0.51¼	1902	1.54	1.15
1867	4.00	1.50	1885	1.12⅝	0.68	1903	1.90	1.50
1868	5.50	1.80	1886	0.92¼	0.60	1904	1.85	1.50
1869	7.00	4.25	1887	0.90	0.54	1905	1.61	1.27
1870	4.90	2.75	1888	1.00	0.71⅜	1906	1.64	1.58
1871	5.15	3.40	1889	1.12½	0.79½	1907	1.78	1.58
1872	4.10	3.00	1890	1.07⅞	0.60¾	1908	1.78	1.78
1873	3.05	1.00	1891	0.81⅜	0.50	1909	1.78	1.43
1874	1.90	0.45	1892	0.64⅛	0.50	1910	1.43	1.30
1875	1.65	0.90	1893	0.80	0.52⅞	1911	1.35	1.30
1876	4.23⅛	1.48¾	1894	0.95¾	0.78½	1912	1.95	1.30
1877	3.70	1.53¾	1895	2.96	0.94½	1913	2.50	2.00

[1] Writing in 1887, Edward Orton, State geologist of Ohio, thus described the production and promise of the Lima field: "Drilling in the Lima field was begun in the spring of 1885. It was a year, however, before the oil producers entered vigorously upon its development. The wells on the Shade farm, south of the town, made the first significant departure from the day of small things with which the work was begun. All these were flowing wells. The early summer of 1886 marked the beginning of rapid development. The production of single wells increased from 60 and 70 bbl. to 100 bbl. a day, and presently, in the Hume well, to 250 bbl. a day, and a little later to 700 bbl. in the Tunget well. To the southward, great wells were presently found. The Ridenour farm, the Hueston, Moore, Ditzler, Ballard, Lehman, Goodenow, and Spear farms all became centers of large and certain production. By Oct. 1 the character of the field had come into clear view as second to none yet found in the United States in volume of production. During September, 1886, 33 wells were added to the 128 previously drilled. Of these one was dry. The total production of the new wells was 2455 bbl. daily, showing an average of 75 bbl. to the well. Six of these wells were

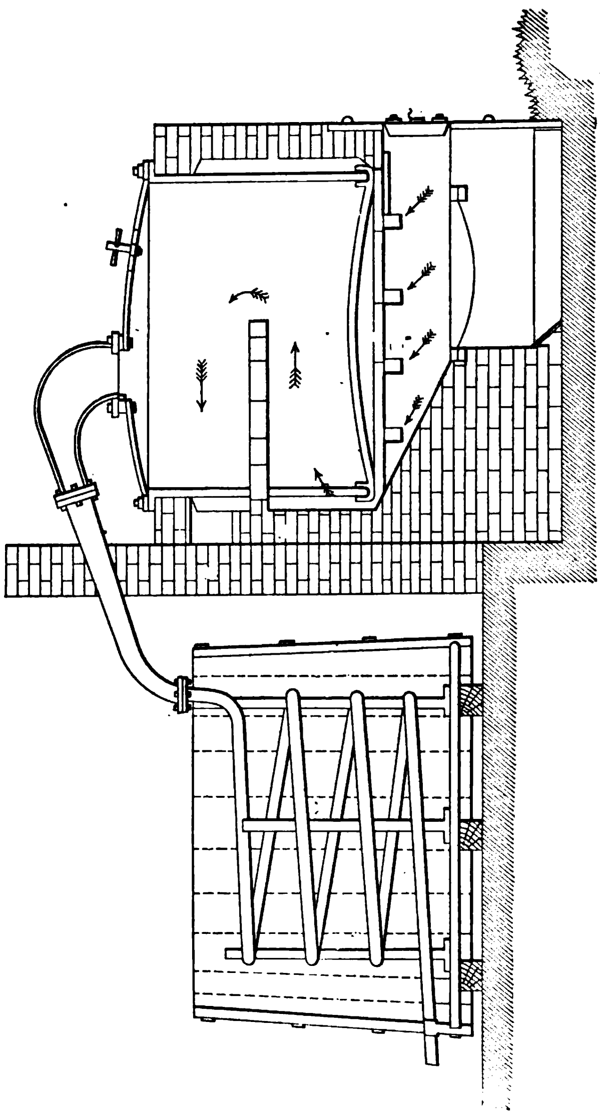


FIG. 45.—Section of still and condenser, such as were used about 1865.

credited with an aggregate production of 1,300 bbl. daily. In November, a number of other great wells was brought in, and the Douglas, Crumrine, Boop, Mechling, McLaid, and other farms were added to the prolific areas. A well drilled during this month on the Alonzo McLain farm, Section 13, Shawnee Township, reached a production for its first day of nearly, or quite, 1,000 bbl. This well is still flowing (1887) at the rate of 150 bbl. a day.

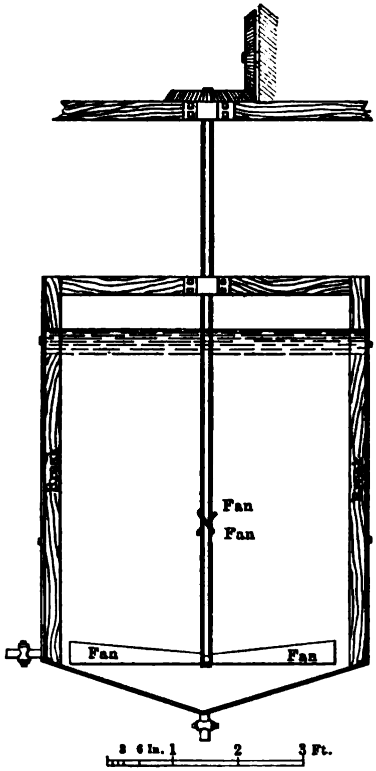


FIG. 46.—The section of a vertical washer of the type in use in 1865.

The largest production in the Lima field for a single day is that of a well on the J. W. Ridenour farm, Section 18, Perry Township. It put into tanks in the first 24 hr. 2,760 bbl. of oil. . . . On the 1st of May there were 444 wells in the Lima fields" (*8th Ann. Rep. U. S. Geol. Survey*, **1890**).

[2] Up to 1876 West Virginia is estimated to have produced 3,000,000 bbl. In 1889, the output from its 623 producing wells amounted to 544,113 bbl., of which the Turkey Foot and Mount Morris fields gave about two-thirds. In 1892, the production was 3,810,086 bbl., while in 1893 it amounted to 8,445,412 bbl. and in 1903 to 12,899,395 bbl., after having reached upward of 16,000,000 bbl. in 1900. From 1903 to 1907 the production steadily declined, and was somewhat in excess of 9,000,000 bbl. in the last of these years. During the following two years there was a slight increase to 10,745,092 bbl. for 1909.

[3] In Kentucky much prospecting was carried on prior to 1890 in Barren, Clinton, Cumberland, Pulaski, Russell, and Wayne counties, but the only production reported in 1889 was from Boyd's Creek, in Barren County, and this amounted to 5,400 bbl. In 1891, 9,000 bbl. were produced, but the

Tennessee,[1] and California.[2] After 1884 the production of Ohio

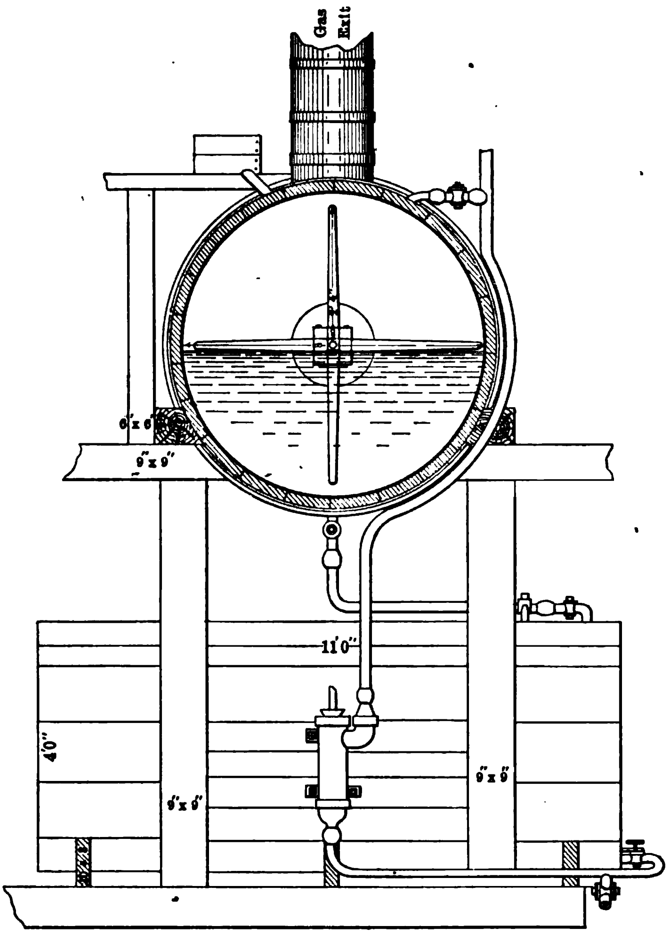


FIG. 47.—The end elevation and section of a horizontal washer and tanks (1865).

output then declined, until in 1897 only 322 bbl. were obtained; the production then began to increase very rapidly until 1905, when the output from Kentucky and Tennessee was 1,217,337 bbl., of which Tennessee only produced about 10,000 bbl.

[1] The operations in Tennessee date from 1893, but for 10 years the only important results were those obtained in the Bobs Bar well, drilled in 1896, which at first yielded 5,000 to 6,000 bbl. annually; practically all the oil produced in Tennessee came from this well down to 1904. In that year some development took place at Poplar Cove, Fentress County, a few miles

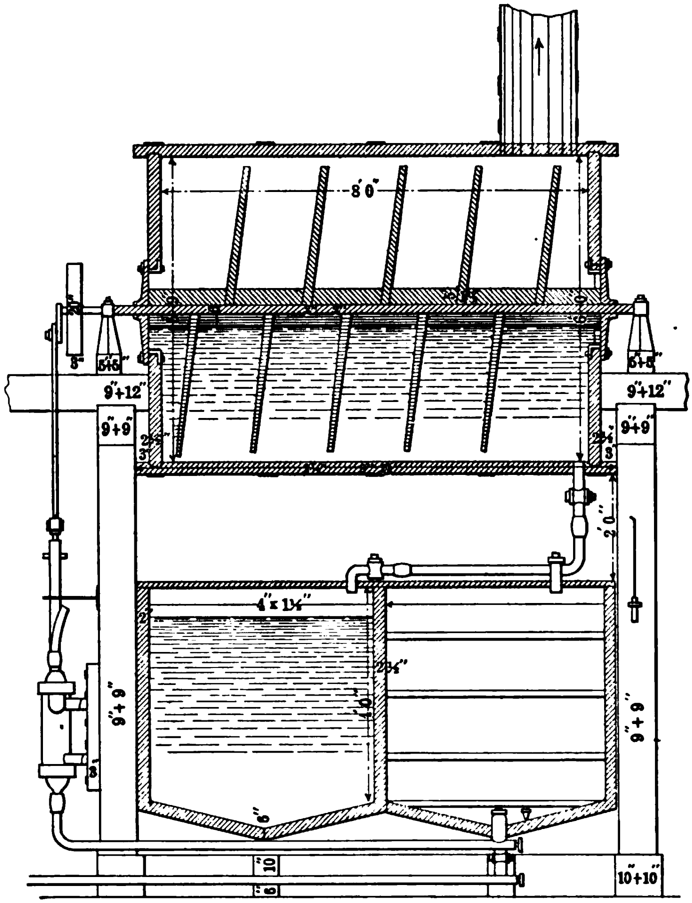


FIG. 48.—The longitudinal section of a horizontal washer and tanks (1865).

north of Bobs Bar, and several good wells were obtained, leading to the extension of the Cumberland pipe line into the new district in 1905. In spite of this, the production declined rapidly; in 1915, however, Tennessee again became a producer.

[2] Until 1881 the production of petroleum in California was not large, the output in 1880 being but 40,552 bbl., mainly derived from Ventura, Los Angeles, and Santa Barbara districts. Since that time it has rapidly increased, and California became first in the rank of petroleum-producing states, the yield in 1903 being nearly 24,382,472 bbl. In 1907 and 1908 Oklahoma produced more petroleum than California, but in 1909 the latter again held first place with 54,433,010 bbl. and in 1910 the production was over 73,000,000 bbl.

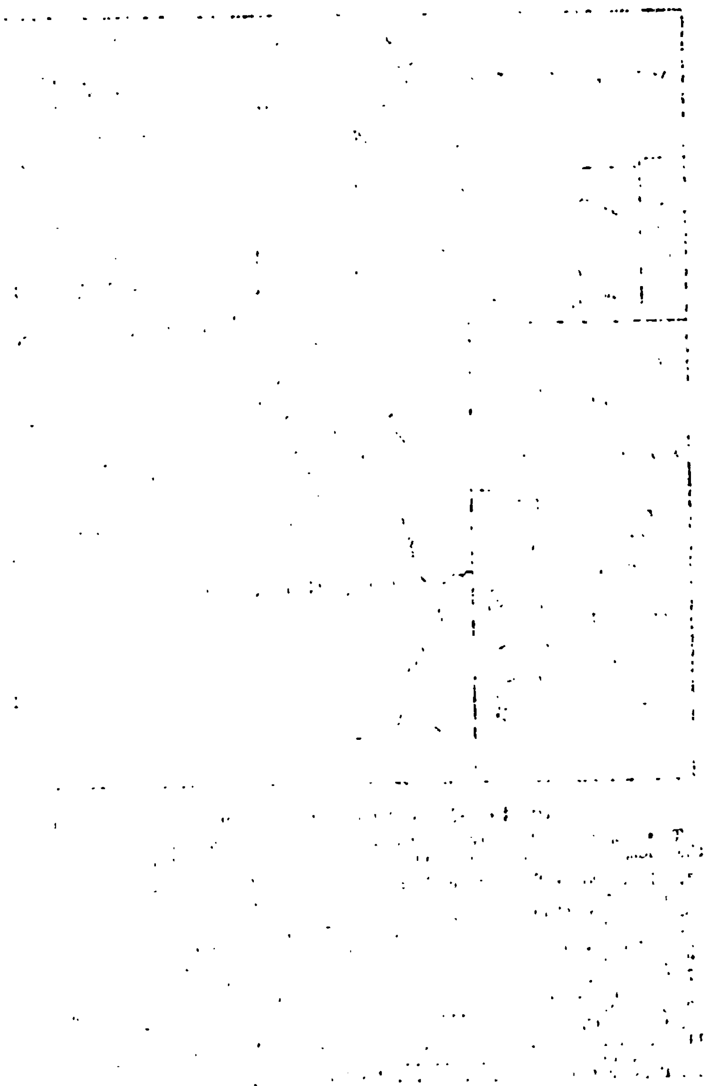
rapidly increased, and that of West Virginia after 1890; from the same date that of California also increased steadily to nearly 30,000,000 bbl. in 1904, and Colorado and Indiana began to contribute appreciable quantities to the total supply. Very small productions were also recorded from Illinois,[1]


FIG. 50.—A West Virginia petroleum well of 1865. Depth, 150 ft. The cost of sinking a petroleum well 600 ft. was estimated, at that time, at $7,000.

In a memorandum on the subject of the duration of the supplies of Californian petroleum, addressed to the Secretary of the Interior, GEORGE OTIS SMITH, the Director of the U. S. Geological Survey, estimates the aquntity of petroleum remaining underground at about 7,000,000,000 bbl.

[1] Down to 1902 the only production of petroleum in Illinois was near Litchfield, Montgomery County, where some 1,460 bbl. were obtained in 1889, and several hundred barrels each year till 1902, when 200 bbl. were obtained. The whole of this oil was used as a lubricant, but no production was recorded in 1903 or 1904.

During the early "oil rush" in Pennsylvania, some wells were drilled in Clark County, Illinois, a few miles north of the town of Casey, at a place called Oil Field, and these were reported to have met with small showings of oil. In 1904, a Pittsburgh group drilled a well very close to these old



Kansas,[1] Texas,[2] Missouri,[3] and Indian Territory at the beginning of the last decade of the nineteenth century, but toward its close, Kansas and Texas began to develop their petroleum resources to a fuller extent, and Wyoming also appeared on the list of producing states.

From 1901 to 1904, while the eastern fields showed a decline, California, Texas, and Louisiana, with the Indian and Oklahoma

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tests, obtaining a slight showing of oil and gas. A second boring resulted in a 35-bbl. well, and in 1905 some 300 wells were drilled, extending the field through Clark to Cumberland and Crawford counties. There were three principal areas, one between Casey and Westfield in Clark, another southeast of Casey, and the third near Robinson in Crawford. The first of these was in 1905 connected by pipe line to the Cincinnati, Hamilton and Dayton Railroad at Oil Field Station. The production in 1905 was 181,084 bbl.

[1] Operations have been carried on in Kansas since 1865, when two wells were sunk about 10 miles east of Paola. In 1873, a boring, 7 miles from Paola, near a large tar spring, met with a strong flow of gas at 320 ft. and was abandoned. In 1888, a very heavy black oil was found, and in May, 1889, a good oil-sand was struck at 330 ft. In 1890, 13 producing wells were in operation in the Russell tract, and in 1894 the output amounted to about 40,000 bbl. More active development then commenced, and in 1896 the production was 113,571 bbl., though it declined in 1899 to 69,700 bbl. After 1900 the industry began to develop with the discovery of new sources of oil at Chanute in Neosho County, and at Humboldt in Allen, the previous production being almost entirely derived from Neodesha in Wilson County.

[2] The first development of the petroleum industry in Texas was in the sixties, when oil was found near Nacogdoches at a depth of about 100 ft., and a few wells flowed to a very limited extent. A pipe line was constructed, and storage tanks built; but the industry remained in a stagnant condition for many years. In 1895, the amount of oil obtained was only 50 bbl. In 1893, however, petroleum had been found at Sour Lake, at a depth of 230 ft., and in 1894 it was discovered near Corsicana, from which neighborhood about 1,000 bbl. were obtained in 1896. In 1897, the output had increased to nearly 66,000 bbl. and the next year to 546,000 bbl.

[3] In Missouri only 20 bbl. of oil were reported as produced in 1889. The product resembled that of Paola, in Kansas, and was all obtained from one well in Boone Township, Bates County. Much prospecting for gas has been carried on in the State, but the only commercially available supplies have been obtained in Bates, Cass, Clay and Jackson counties. The wells are about 400 ft. deep, and are supplied by a reddish sandstone from 10 to 40 ft. thick, which sometimes also contains a thick black oil. Gas to the value of $35,687 was produced in 1889, but only to the value of $2,154 in 1902, which was, however, more than in any year since 1895. In 1902, oil of good lubricating quality was found at Belton, Cass County, together with natural gas, which is utilized for heating and illuminating purposes. The gas was obtained at a depth of 366 ft., and the oil from 340 to 490 ft.

Territories, Kansas, and Indiana,[1] increased their production to a remarkable extent. Down to the end of 1904 the entire output of petroleum in the United States since its discovery in quantity in 1859 was estimated at 1,382,815,006 bbl., which sold for $1,363,069,897, an average price of 98.6 cts. per barrel.[2]

According to the annual reports of the United States Geological Survey, the most important features in connection with the production of petroleum in this country during the five years 1904–1909 were as follows.

In 1904 there was a continuation of the remarkable increase in the production of an inferior grade of petroleum in California, Texas, and Louisiana, and of the increase in Kansas and Indian Territory of the production of a fair grade of petroleum; for the first time in the history of the petroleum industry the quantity produced west of the Mississippi River was greater than that produced east; there were new fields developed in Texas, California, and Kansas; the regularity of the sum of production of the older fields continued to be remarkable; there was an increase in the demand for refined petroleum throughout the United States, especially for the lighter grades used in internal-combustion engines, and there was an increased quantity of the heavier crude petroleum produced in Louisiana, Texas, and California consumed as fuel.

In 1905, the development of the Mid-Continent field and the extension into Illinois of the Lima-Indiana field indicated a great increase in the future production of the lighter grades of oil, while the production of the eastern fields showed signs of permanent decrease. The completion of the pipe line from Humboldt, Kansas, to Whiting, Indiana, marked another step in

[1] The oil industry of Indiana developed with remarkable rapidity between 1891 and 1904, but since that date the production has declined with even greater speed. In 1871, T. Sterry Hunt (*Am. Nat.*, **5**, 576) stated that a well sunk at Terre Haute for water was carried to a depth of 1,900 ft. and yielded about 7 gal. of oil daily. A second well, a quarter of a mile east-by-north from the first, yielded 25 bbl. daily, at a depth of 1,625 ft. For many years only very small results attended the efforts of prospectors. The output during 1889 from the districts of Terre Haute in Vigo County and Montpelier in Blackford County, the only fields included in the Eleventh Census Report, was 33,375 bbl. In 1890, the output from the whole of Indiana was 63,496 bbl.; in 1891, 136,634; in 1892, 698,068; in 1893, 2,335,293 bbl. And from that time it steadily increased to 5,757,086 bbl. in 1901, and 11,339,124 bbl. in 1904. The production in 1909 was only 2,296,086 bbl.

[2] Oliphant, *Mineral Resources of the United States*, **1904**.

the transportation of oil. In 1906, there was an extension of the area of the Mid-Continent field, and an increase in the daily production of oil in that region; an expansion of the area in Illinois from which oil was being produced; considerable growth in the consumption of fuel oil in California; decline in the production from the Coastal Plain district of the Gulf States; and further decrease in the average daily production from the Appalachian field. Additional transport facilities were provided by the laying of a second pipe line across the Isthmus of Panama for the delivery of the oil from the Californian field to the Atlantic Ocean. In 1907, there was a total output of crude oil far in excess of that of any previous year, with an unparalleled ac-

FIG. 51.—The north extension of the Cushing field (1915).

cumulation of stocks; and great increase in production in the new Illinois field, in the Glenn pool in Oklahoma, and in California. In 1908, there was a steady growth in the production in Illinois and California, and a decline in the production in the Glenn pool and in various Texas and Louisiana pools. In 1909, California was the chief center of attraction, the production increasing to the extent of 21.35 per cent., but Oklahoma and West Virginia also showed some gain. In 1910, a further increase of 31.62 per cent. was recorded in California, and Louisiana more than doubled its output; the production of oil in Wyoming also began to assume importance.

The Cushing pool, in Oklahoma, was extended in various directions in 1913; its output decreased for a few months, and

then, with active drilling to establish extensions on the south, southeast, and north, the product, which had declined from 30,000 to 16,000 bbl., gradually rose again to over 30,000 bbl. a day. Just at the close of the year a well on the edge of the Cushing region was drilled 600 ft. deeper, to the Bartlesville sand, and a sensational flow was encountered. This started the general policy of drilling to the thick and prolific Bartlesville sand, and oil came with a rush. Stocks were accumulating heavily at the end of the year. Late in September a small amount of oil was obtained in a well drilled near Healdton, Carter County, in the southern part of the State. By the close

Fig. 52.—Oilton, Oklahoma, on January 20, 1915. (Courtesy of Edward E. Bartlett, Sapulpa, Okla.)

of the year several other wells had been drilled in that locality which were sufficiently successful to arouse the excitement that proved justified in 1914. The prices of Mid-Continent oil began to decline on Apr. 8, 1914; and as the ever-increasing flood of Cushing petroleum began to invade the markets of the Appalachian crudes, they, too, began a retrograde movement on Apr. 17, 1914.

At the close of 1912, consumption in California had so nearly balanced production as to encourage the producers and to defeat concerted effort toward the restriction of drilling. Many of the wells of 1913 were gushers of the phenomenal type and aided greatly in increasing the supply. The efforts to increase

consumption succeeded fairly well, so that, except during the month of greatest production, September, when about 9,000,000 bbl. were produced, consumption almost kept pace with output and the quantity sent to storage was less than 1,000,000 bbl. The Fullerton field continued to yield large gushers with sufficient frequency to justify the expense in reaching the unusual depth of the oil sands. The "West Side" fields of Kern County continued as strong factors in increasing the output of the State, and the Buona Vista Hills, Elk Hills, and other new districts gained in interest. Even the comparatively old Kern River field, near Bakersfield, sustained interest by wildcatting

FIG. 53.—Oilton, Oklahoma, on March 20, 1915. (Courtesy of Edward E. Bartlett, Sapulpa, Okla.)

to the northwest, where the Standard Oil Company's well went into oil and aroused geologic and financial speculation over a large area. The product of the field, however, declined. Coalinga's year had many eventful features, including extensions of territory to the east and the discovery of additional deep sands yielding oils containing paraffin. In 1914, California markets, though exempt from the specific influences affecting markets in the Eastern States, were, however, subjected to depressing influences of local origin, resulting from an increased output of lighter gravity oils in the Whittier-Fullerton district.

As to Texas and Louisiana, the Electra and the Burkburnett fields in Texas progressed satisfactorily in 1913, and a new field

was developed at Moran, in Shackelford County. In the Gulf field, Sour Lake furnished a surprise by yielding gushers sufficient to increase the total yield and to contribute to a decline in prices. It became evident during the year that the prospects of increase in the Gulf region, together with the abundant Mexican field, presage a plentiful supply of fuel oil. The Caddo field proved as irregular as in previous years, but gushers were so frequent and so large as to keep up the supply. To the south the De Sota region furnished several large gushers. The consequent excitement was tempered by the advent of water from a substratum, but the importance of the region was demonstrated.

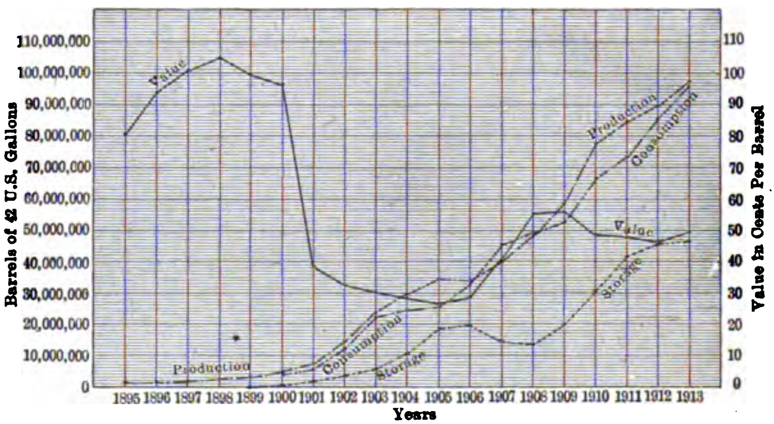


FIG. 54.—The relation of price, storage, consumption, and production of California crude petroleum, 1895–1913.

The study of the domestic production of petroleum yields a story of progressive maxima, until in 1913 the product reached 248,446,230 bbl., or 33,126,164 metric tons. The yield of 1912 was 222,935,044 bbl., or 29,724,673 metric tons. Although the product of 1912 exceeded all previous records, the yield of 1913 surpassed it by the greatest gain in any year since 1910. In fact, the increase of 1913 over 1912—more than 25,000,000 bbl.—was greater than the total production in any year until 1880, and the output of 1913 equaled the total production of the United States for the first 25 years of the industry. The production of the United States in 1913 was greater than the world's production in 1906.

Still more remarkable in regard to the growth of the domestic oil industry is the amount of money received by the producers.

In 1912 this amounted to $164,213,247, or an average of 73.7 cts. a barrel, and in 1913 this average was 95.4 cts. a barrel, or a total of $237,121,388, a gain of $72,908,141 over 1912. This was the greatest gain for any year in the history of the industry, and the gain alone outvalued the total receipts for oil in any year up to and including 1899 and was greater than the value of the oil in all years combined up to and including 1866.

Measured by the marketed production (265,762,535 bbl.) the year 1914 was the greatest in the history of the crude petroleum industry. Second in importance to the phenomenal yield of petroleum in 1914 was the trend of the crude oil market during that year, which was characterized by a depreciation in price affecting in varying degrees every type of high-grade oil produced.

Statistics show the quantity of oil produced in the United States from the beginning of the industry in 1859 down to the end of 1914 to be 3,335,457,140 bbl. and the total value to be $2,789,829,745. According to John D. Northrop, of the United States Geological Survey, the marketed production of petroleum in the United States in 1915 approximated 267,400,000 bbl., and the total yield approximated 291,400,000 bbl., about 24,000,000 bbl. of oil brought to the surface during the year being placed in field storage by the producers.

In 1914, the conditions of oil production in the United States developed into a position involving in all probability radical change in the economic conditions of the oil industry. The production and the known productive capacity of the oil lands in Oklahoma increased beyond all expectation and reasonable demands, and the extension of oil fields in Texas and Louisiana indicated a possibility of further floods of oil that would require a rearrangement of the productive system. The condition in Oklahoma threatened the axiom that "oil has an instant spot value." So long as oil can be taken from the ground and sold for more than the cost of production, so long will active drilling be continued and so long will agreements as to limiting production fail. The point at which the exploration for oil in a new region is no longer logical and the drilling should, therefore, naturally cease, depends upon the yield of the wells when drilled. Oil was probably profitable at 10 cts. a barrel in Texas in 1901 on account of the size of the wells yielding it at Spindletop. But at this price all pumping wells would now be unprofitable, and even small flowing wells would not tempt the driller. It is

the uncertainty of the size of the well which may be obtained that tempts the speculators in a new region and clouds any clear and rational plan of development of oil territory. The speculative tendency is well illustrated by the fact that in many parts of the United States (*e.g.*, in Colorado and Nevada) oil-shales[1] could be mined and distilled for the production of oil on a basis as safe and sane as the mining of coal. Nevertheless, few prominent oil producers would leave the speculative thrill of the oil fields for the unexciting development of oil-shales.

According to the United States Geological Survey, the solution of the problem of sufficient stock of oil for the enormous refining capacity of the United States must in the future rest chiefly on more accurate knowledge of the supplies of oil under ground, and, based upon this, the consequent application by the State of rigid rules whereby it shall become impossible for one operator to interfere with the oil contained in the property of another.

The Transportation of Petroleum.[2]—One of the first problems which confronted the oil producer was that of transportation. The oil wells along Oil Creek and the Allegheny River, in Pennsylvania, were many miles from a railroad, in a lumber district where there were often no roads, or at best very poor ones, scarcely more than trails. Oil City was the nearest shipping point and Pittsburgh was the largest distributing center. Crude oil was put into iron-hooped barrels made of oak and holding 40 to 42 gal., was loaded on trucks, and then hauled to Oil City. Barges were then loaded with barreled oil or were made into tank boats and the load floated down Oil Creek to the Allegheny River at Oil City. During most of the year Oil Creek was, however, a shallow stream, and the novel plan of slack-water navigation was resorted to. The water in the streams tributary to Oil Creek was held back by dams until sufficient quantities

[1] See pp. 807 to 844.

[2] For a general consideration of the transport of petroleum, see CALMEL, *J. Pétr.*, **1** (1901), 3, 21, 40, 55, 71; on its transport in bulk, see FLANNERY, *Proc. Second Internat. Marit. Cong.*, **1893**, sect. B, 62; and HENRY, *Compt. rend. Cong. Internat. Pétrole, sess.* 3, **2**, 853 (1910); on the evolution of the tank steamer, see HENRY'S "Thirty-five Years of Oil Transport," London, **1907**; on the transport of petroleum in Pennsylvania about 1880, see HERRMANN, *Wochenschr. Ver. Deutsch. Ing.*, **1880**, 393; G. H. LITTLE is the author of a work on "The Marine Transport of Petroleum," London, **1890**; REDWOOD has discussed the subject at length in *Proc. Inst. Civ. Eng.*, **116** (1894), 177. See also p. 450.

had accumulated; and then, at a fixed hour, each body of water was in turn released, filling the main stream for a short time with a flood. On this the barges of oil were carried down to their destination, warning having been given so that the boatmen along the stream might be ready to take advantage of the tide as it passed.

In 1862, the Atlantic and Great Western Railroad was extended into the oil region. In 1866, the Allegheny Valley Railroad was

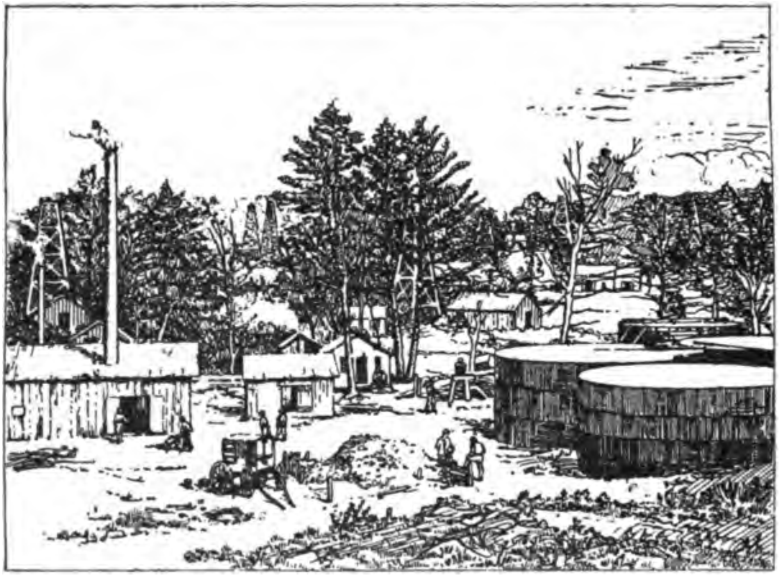
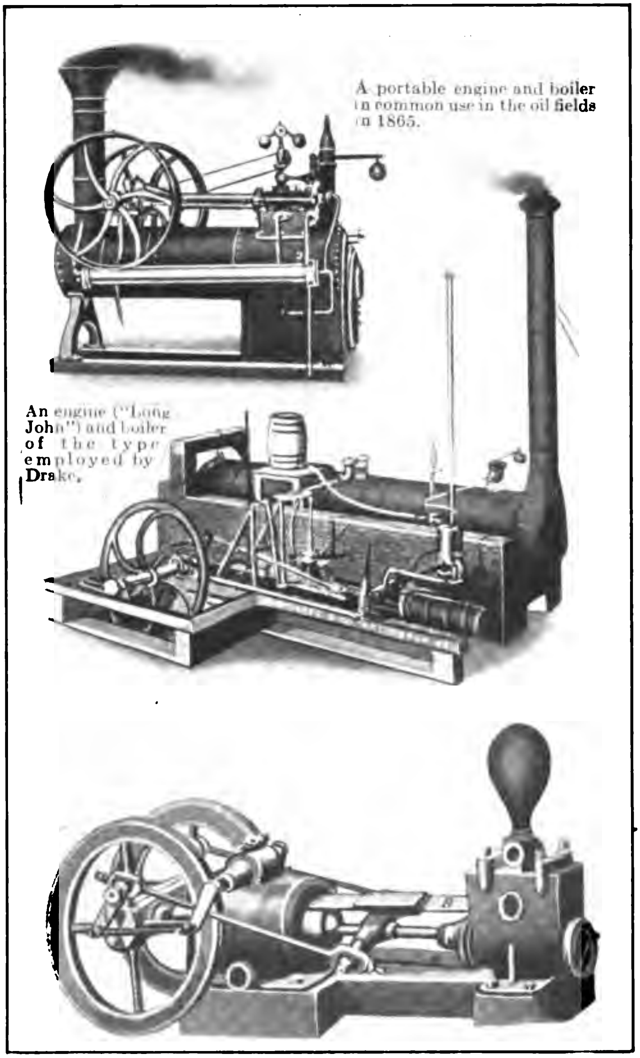


FIG. 55.—The first large pumping station erected in the Pennsylvania oil regions. This was located at the National Wells, about two and one-half miles from Pleasantville, and was operated by the Titusville and Tidioute Piping Line Company. The station was equipped with a 50-hp. Woodbury and Booth boiler, and a 30-hp. portable boiler, and with two Niagara pumps. Petroleum was pumped to Titusville, Tidioute, and Pithole. (Henry's "History and Romance of the Petroleum Industry.")

opened up from Oil City, at the mouth of Oil Creek, to Pittsburgh, and a number of narrow-gauge lines were constructed as feeders into the heart of the producing country. At first the barrels were loaded on flat cars; but the leakage was so great that wooden tank cars were built in 1865, which had two wooden tubs or vats, each holding about 2,000 gal., placed on an ordinary platform car. In 1871, cars consisting of a horizontal cylindrical tank of boiler plate, mounted on a four-wheel platform or rail-

road truck, appeared.[1] These were at first of no greater capacity than the wooden cars they displaced, but have been gradually



One of the steam pumps manufactured by Reed and Cogswell, engineers, Liberty Street, New York, for use on the first pipe line.

FIG. 56.—Engines and pumps in use during the early development of the oil fields of northwestern Pennsylvania.

increased in size, until many are now of 8,000 gal. capacity each.

[1] There were, in 1873, on all the railroads that handled petroleum, about 2,500 iron bulk cars, of an average capacity of 85 bbl. to a car.

But the magnitude of the petroleum industry made it necessary to find some mode of transportation even cheaper than a railroad, and the pipe line displaced the car and boat. The introduction of this mode of transporting oil marks an era in the petroleum industry. When this system was introduced, the cost of transportation was so much reduced that a few enormous refineries were built at the seaboard near New York, Philadelphia, and Baltimore, and on the shores of Lake Erie, near Buffalo and Cleveland, to accomplish what the almost countless small refineries in the oil region had heretofore done.

S. D. Karns, in November, 1860, proposed to lay a 6-in. pipe from Burning Springs to Parkersburg, W. Va., through which the oil would flow by gravitation to the Ohio River, a distance of 35 miles. This pipe line was never constructed; but in 1862 L. Hutchinson, of New York, laid a line on the Tarr Farm to convey the petroleum over a hill to the refinery, on the syphon principle, and a year later constructed another, 3 miles long, from the Sherman well to the railroad at Miller Farm. This line was provided, at intervals of every 50 or 100 ft., with air chambers to equalize the pressure; but the excessive leakage at the joints of the pipes rendered this and Hutchinson's previous attempt unsuccessful.

In 1865, Samuel Van Syckel, of Titusville, Pa., put down a working line, the sections of which were joined by carefully fitted screw-sockets. It was only 4 miles long, extending from Pithole to the railroad at Miller's farm, and carried but 80 bbl. per day. It demonstrated, however, the thorough practicability of transporting petroleum in this way. This line, together with another laid by Henry Harley in 1865 to 1866 from Benninghoff Run to the Shaffer farm, passed into the control of a corporation known as the Allegheny Transportation Company, by which it was operated.[1] Lines were first laid only to the refineries in the oil region and to the railroads taking the oil out of the region. With the lengthening of the pipes and the increase of pressure to force the liquid to greater distances, an organization called the Pennsylvania Transportation Company in 1875 obtained a

[1] The owners and drivers of oil wagons saw that this mode of transportation must soon deprive them of occupation, and they cut the lines, set fire to the tanks with which they were connected, and even threatened the proprietors and managers with personal violence. An armed patrol and the arrest of the ringleaders by detectives soon quelled this outbreak.

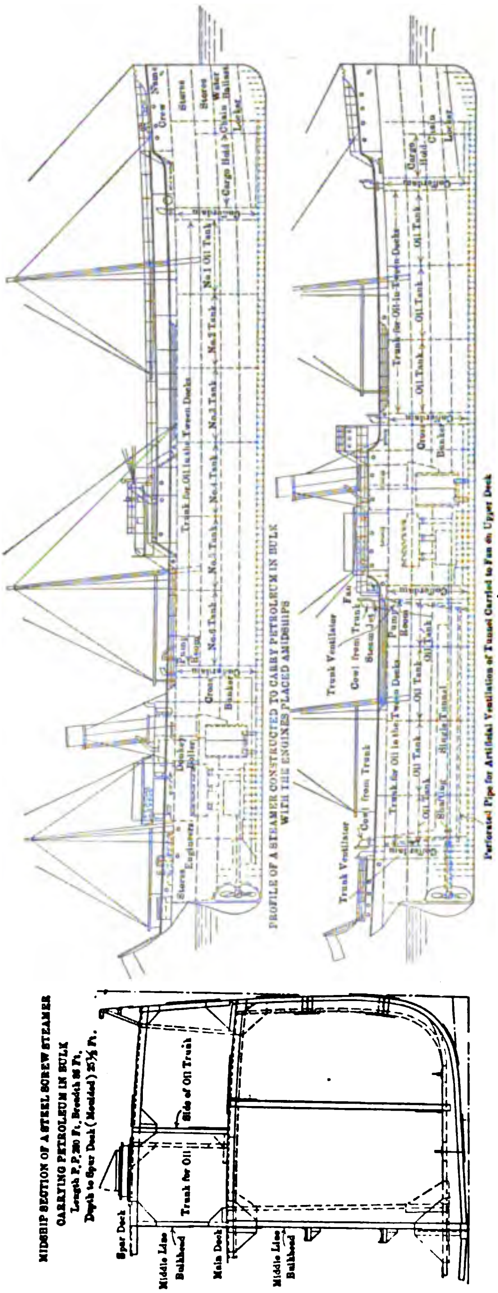


FIG. 57.—Profiles of steamers constructed to carry petroleum. (Martell, *Trans. Inst. Naval Arch.*, **35**, 1).

charter with power to construct a pipe line to the seaboard. The only outcome of this venture was the building of various lines within the oil region. Short lines multiplied, and pipe after pipe from the producing fields to the refineries and railroad shipping points crossed and paralleled one another in every direction. Competing companies waged war upon one another, cutting rates to the point where business was done at an actual loss. The United Pipe Lines Association, first known as the Fairview Pipe Line, organized by J. J. Vandergrift and George V. Forman, became the starting point for concentration. Into it were merged, from time to time, the other local lines. The first trunk line was laid in 1874 from the lower oil country to Pittsburgh; it consisted of 60 miles of 4-in. pipe. The trunk line to Cleveland next followed. Pipe lines were then extended from the Pennsylvania oil fields to Cleveland, Buffalo, New York, Philadelphia, and Baltimore; and from the Ohio fields to Cleveland and Chicago. The conveyance of crude petroleum to these centers rapidly acquired such importance that a combination was effected among the United Pipe Lines Company, the Standard Oil Company of Cleveland, the American Transfer Company, and others, the National Transit Company being thus formed. Subsequently a number of additional trunk pipe line companies were organized.[1]

[1] The pipe lines of the United States, comprising those of seventeen subsidiary companies of the Standard Oil Company, and eight independent lines, owned and operated pipe lines, were estimated by the United States Bureau of Corporations in 1907 to total more than 45,000 miles of pipe ranging from 2 to 12 in. in diameter. The majority of the lines are 6 or 8 in. in diameter. The longest continuous line reaches from Oklahoma to New York City. See *Report of the Commissioner of Corporations on the Transportation of Petroleum*, May, 1906. In the Kansas and Oklahoma oil fields, there were in September, 1913, 1382 tank cars in use among refiners and small shippers. In addition to the cars owned by the railway companies, the Standard Oil Company and the Texas and Gulf Companies, certain other refining companies had a large number of tank cars in these states and they were used also in connection with eastern plants. In 1904, the Union Tank Line Company, a subsidiary of the Standard Oil Company, had about 9,000 tank cars, while the Waters-Pierce Company had about 1000. The capacity of the tank cars in the Kansas and Oklahoma fields ranges from 4,000 to 10,000 gal. (see also p. 452).

By sea, crude petroleum is transported in tank steamers or tank barges. Fuel oil from the Texas and California fields is piped to the seaports and distributed to the various markets by tank steamers. From the eastern seaboard of the United States some crude oil is shipped to Europe in tank

In 1907, the rifled pipe line was introduced. This pipe line, the invention of J. D. Isaacs and Buckner Speed, has greatly facilitated the transport of the more viscous crude petroleums; it is provided with spiral grooves, or rifling, through which a lubricating current of water is pumped with the oil.

FIG. 58.—Tank steamers of the Gulf Refining Company.

steamers and in tank sailing vessels, but the main employment of tank steamers is for shipping in bulk refined oils, as kerosene. On the Caspian sea, early in 1913, there were 168 vessels engaged in the transport of oil to and from different parts of the Russian empire. The vessels fitted with Diesel engines, owing to their low consumption of fuel, are replacing the other forms of power boats. Since 1905 the Standard Oil Company has also used tank barges. A tank steamer carrying 400 tons of oil tows a tank barge carrying 6,000 tons of oil, by means of a 600-fathom steel-wire hawser, fitted with winding drums which automatically take in or pay out the hawser depending on the strain upon it. Both steamers and barges are constructed entirely of steel, divided into compartments by bulkheads and provided with means of escape for the oil gases, and with supply tanks to make up any loss of oil in the tanks by leakage or evaporation. On tank ship construction, see MORRELL, *Int. Marine Eng.*, **1915**, 71.

Where an oil field has a small yield, as when a small output of oil is incidental to natural gas production, and the market is purely local and the oil is used in a crude state, the means of transportation and distribution are likely to be correspondingly simple and primitive. For instance, in the gas fields of New Brunswick some of the wells yield a few gallons of petroleum per day. This is piped to a loading tank by the roadside, from which it is transferred to tank wagons which distribute it.

Some heavy lubricating, or otherwise peculiarly valuable oils which do

Statistics of Production.—The production and value of petroleum, well records, and acreage for the United States in 1914, by states, from statistics supplied by the United States Geological Survey, are given in Table XXXI.

The production of crude petroleum in the United States, from given 1859 to 1914, by years and by states, in barrels of 42 gal., is in Table XXXV., which illustrates the historical development of the industry in this country.

For the sake of comparison, there is provided Table XXXVI., showing the world's marketed production of crude petroleum, from 1857 to 1914, by years and by countries, in barrels of 42 gal. This table serves as a presentment, in abstract, of the general history of the petroleum industry.

Exports of Petroleum.—Practically all forms of petroleum products, from crude oil to paraffin wax, form part of the export trade of the United States, and petroleum products in one form or another, especially kerosene, reach all parts of the world.

Between 4,000,000 and 5,000,000 bbl. of crude oil are exported each year; and in 1913 about 200,000,000 gal. of gasoline and naphtha, slightly over 1,000,000,000 gal. of illuminating oil, over 200,000,000 gal. of lubricants, and over 300,000,000 gal. of gas oils, and more than 27,000,000 bbl. of residuum were exported. In all, reduced to barrels, the exports amounted to 50,868,231 bbl. in 1913 , or 20.5 per cent. of the total production. The total exports of petroleum and its liquid products from the United States in 1914 amounted in value to $139,900,587.

This trade, which represents essentially the overflow of prod-

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not occur or are not purchased in quantity sufficient to make a separate run in a pipe line or even to justify shipping in a tank car, or which are destined to points away from railway or pipe-line facilities, are shipped in wooden barrels or more generally in steel drums; but now on land the great bulk of the petroleum products are transported in pipe lines, with smaller quantities in tank cars, and, on the ocean, in tank steamers.

Refined oil products, lubricating oil, kerosene, gasoline and the like, when shipped by rail, are transported in tank cars, in wooden barrels, in steel drums, or in tin cans. Towns on a railway and large enough to support a distributing wagon service, have receiving storage tanks adjacent to the railway switch and the oil is pumped into these tanks from the tank cars. Smaller towns, especially those without railway communication, are usually supplied with oil in wooden barrels. In the western part of the country considerable oil is shipped in tin cans in wooden cases, each container holding two cans, each of 5 gal. capacity. Much kerosene is shipped to foreign countries in such cans.

TABLE XXXI.

State	Production (in barrels)				Average price per barrel	Wells					Average daily production (in barrels) per well	Acreage		
	Placed to credit of—		Total	Value		Productive Jan. 1	Completed		Abandoned	Productive Dec. 31		Fee	Lease	Total
	Producer	Landowner					Oil	Dry						
Alabama	....	....	....	....	....	....	....	3	....	....	....	3,049	....	3,049
Alaska	....	....	(a)	(a)	....	7	1	....	....	8	....	148	9,000	9,148
Arkansas	....	....	....	....	....	....	....	1	....	....	....	800	43,258	44,058
California	95,118,988	4,656,339	99,775,327	$48,066,096	$0.482	6,817	512	47	197	7,132	38.3	348,592	127,249	475,841
Colorado	222,591	182	222,773	200,894	0.902	92	12	10	14	90	6.8	17,065	28,165	45,230
Illinois	18,228,181	3,445,235	21,673,416	24,775,050	1.143	14,100	953	227	253	14,800	4.0	3,479	293,095	296,574
Indiana	1,134,943	183,357	1,318,300	1,291,077	0.979	3,814	434	119	852	3,396	1.1	11,139	88,842	99,981
Kansas	2,167,376	267,569	2,434,945	1,823,050	0.749	3,054	552	156	194	3,412	2.0	21,450	261,386	282,836
Kentucky	430,374	52,738	483,112	483,930	1.002	968	125	41	61	1,032	1.3	8,778	200,302	209,080
Louisiana	11,885,301	2,106,320	13,991,621	12,497,059	0.893	986	327	110	137	1,176	32.6	18,726	491,416	510,142
Michigan	....	....	(a)	(a)	....	26	2	....	2	26	....	14	4,040	4,054
Mississippi	....	....	....	....	....	....	....	2	....	....	....	19,080	47,000	66,080
Missouri	....	....	(a)	(a)	....	12	....	3	....	12	....	....	17,812	17,812
New Mexico	....	....	(b)	(b)	....	2	....	1	1	1	....	80	4,700	4,780
New York	851,402	62,737	914,139	1,588,261	1.737	10,681	638	9	214	11,105	0.2	39,062	78,039	117,101
Ohio	5,813,151	1,421,208	7,234,359	10,918,741	1.509	31,208	1,731	292	1,176	31,763	0.6	56,693	948,947	1,005,640
Oklahoma	70,954,984	10,463,970	81,418,954	60,268,824	0.740	24,085	4,492	1,071	783	27,794	8.0	222,599	1,825,874	2,048,473
Pennsylvania	6,945,584	713,083	7,658,667	15,789,754	2.061	55,294	(c)3,645	265	609	58,330	0.4	306,229	695,245	1,001,474
Texas	17,459,728	2,134,074	19,593,802	13,057,412	0.666	3,542	656	310	347	3,851	13.9	226,478	586,468	812,946
Utah	....	....	(b)	(b)	....	9	....	1	4	5	....	14,717	1,680	16,397
Washington	....	....	....	....	....	1	....	3	....	1	....	6,285	6,000	12,285
West Virginia	8,458,861	1,219,746	9,678,607	17,735,464	1.832	14,544	1,130	218	742	14,932	1.8	98,863	2,508,663	2,607,526
Wyoming	3,547,899	16,476	3,564,375	1,679,192	0.472	198	86	28	21	263	37.1	21,496	74,752	96,248
Others(d)	7,738	54	7,792	14,291	1.834	....	....	....	....	....	0.5	....	....	....
Total	243,227,101	26,743,088	269,970,189	210,189,095	0.779	169,440	15,206	2,917	5,607	179,129	4.1	1,444,822	8,341,933	9,786,755

(a) Included in "Others." (b) No production. (c) Includes many wells previously abandoned but cleaned out and made productive during 1914. (d) Includes Alaska, Michigan, and Missouri.

ucts beyond the consumptive requirements of the United States, is capable of an enormous expansion, if, as Day has indicated,[1] one considers the following table compiled by Boverton Redwood, which shows the consumption of kerosene per head of population in various countries in 1911.

TABLE XXXII.—CONSUMPTION OF KEROSENE DURING 1911 PER HEAD OF POPULATION BY COUNTRIES

	Gallons		Gallons
United States	7.3	Rumania	1.8
Canada	4.0	Austria	1.8
England	3.9	Japan	1.6
Germany	3.6	Brazil	1.2
Australia	3.4	Italy	1.0
France	2.5	Mexico	0.7
Russia	2.0	India	0.6
South Africa	2.0	Spain	0.5
Egypt	1.9	China	0.4

In spite of the use of electricity and gas for illumination in the United States, the use of kerosene is shown by this table to amount to 7.3 gal. per year for every person in the United States. The quantity used in other countries is in every case less; 4 gal. per capita in Canada comes next to the United States, and England requires practically the same quantity. There is a marked decline of the per capita used in other countries; and when one considers that China with its enormous population consumes only 0.4 gal. per capita, the quantity of kerosene which might be sold before the total Chinese consumption per capita would be brought up to the level of that of the United States would equal 11,000,000,000 gal. per annum, or ten times the quantity now exported from the United States, or about three times as much kerosene as is yielded by the total quantity of crude oil produced in the United States. Day maintains that despite our rapidly increasing production, petroleum must be recognized as a limited mineral resource in the world, and that the responsibilities for properly conserving the supply are evident from these considerations.

The following table, compiled from the records of the Bureau of Foreign and Domestic Commerce, show the quantity and declared value of petroleum and its liquid products (mineral oils) exported from the United States in the years 1913 and 1914.

[1] *Mineral Resources of the United States*, **1913**, ii, 1082.

TABLE XXXIII.—EXPORTS OF MINERAL OILS FROM THE UNITED STATES IN THE CALENDAR YEARS 1913 AND 1914, BY KIND AND PORT

Kind and port	1913		1914	
	Quantity	Value	Quantity	Value
Crude	Barrels		Barrels	
New York	1,174,017	$3,957,755	507,799	$1,667,949
Philadelphia	6	38	....	....
Galveston	495	1,503	....	....
Other districts	3,455,712	4,488,998	2,462,095	3,290,889
Total	4,630,230	$8,448,294	2,969,894	$4,958,838
Naphtha	Gallons		Gallons	
Baltimore	62,965	$11,617	52,218	$6,478
Boston and Charlestown	44,381	8,585	30,182	4,634
New York	102,869,333	16,872,213	104,489,412	14,053,210
Philadelphia	23,053,365	3,348,437	24,284,157	2,786,555
Galveston	35,911	5,346	42,225	5,555
Other districts	61,977,424	7,845,410	80,794,461	8,431,982
Total	188,043,379	$28,091,608	209,692,655	$25,288,414
Illuminating	Gallons		Gallons	
Baltimore	139,282	$14,199	900,124	$57,000
Boston and Charlestown	108,963	11,668	88,246	9,742
New York	538,619,277	40,100,916	467,633,204	34,736,938
Philadelphia	229,282,278	13,890,288	142,498,871	9,029,794
Galveston	165	20	20,000	2,125
Other districts	351,291,278	18,025,016	400,308,808	20,277,173
Total	1,119,441,234	$72,042,107	1,011,449,253	$64,112,772
Lubricating and Paraffin	Gallons		Gallons	
Baltimore	12,115,947	$1,648,470	8,135,368	$1,164,547
Boston and Charlestown	94,506	18,972	102,923	21,068
New York	138,778,365	20,227,289	139,412,476	18,822,914
Philadelphia	43,095,432	5,243,542	29,468,223	3,587,246
Galveston	552,276	114,154	268,076	51,859
Other districts	13,002,566	2,356,122	14,260,504	2,668,679
Total	207,639,092	$29,608,549	191,647,570	$26,316,313
Residuum	Gallons		Gallons	
Baltimore	....	....	1,424,281	$42,894
Boston and Charlestown	2,505	$263	105,550	4,780
New York	37,109,808	1,428,062	103,433,079	3,817,903
Philadelphia	20,220,194	742,123	18,622,616	846,572
Galveston	252	72	....	....
Other districts	369,539,614	8,955,331	579,923,095	14,512,101
Total	426,872,373	$11,125,851	703,508,621	$19,224,250
Grand Total	2,136,465,721	$149,316,409	2,240,033,652	$139,900,587

Recapitulation by Kinds

	Gallons		Gallons	
Crude	194,469,634	$8,448,294	124,735,553	$4,958,838
Naphtha	188,043,379	28,091,608	209,692,655	25,288,414
Illuminating	1,119,441,243	72,042,107	1,010,449,253	64,112,772
Lubricating and paraffin	207,639,092	29,608,549	191,647,570	26,316,313
Residuum	426,872,373	11,125,851	703,508,621	19,224,250
Total	2,136,465,721	$149,316,409	2,240,033,652	$139,900,587

Imports of Petroleum.—For many years occasional importations of crude petroleum, and, more frequently, of some special product have been received in the United States, but without any particular bearing upon the trade. The first significant imports were those of gasoline from Borneo to the Pacific coast, to supply the deficiency which then existed for gasoline for the growing automobile consumption. The considerable supply now attainable of lighter oils, of which the production is rapidly increasing in California, will, without doubt, stop these imports of gasoline.

In 1911, the importation of crude petroleum from Mexico began to assume significant proportions and rapidly increased in 1912 and in 1913. In 1914, 17,247,483 bbl. of crude petroleum were imported; practically all of this came from Mexico, and was brought in for use directly as fuel, or for refinery treatment in the manufacture of oil, asphalt, paving cements, roofing material, rubber substitutes and solvents. Small quantities of crude petroleum for experimental or special limited purposes were entered for consumption in 1914 from Canada, Peru, Trinidad, England, Belgium, and Germany.

TABLE XXXIV.—QUANTITY AND VALUE OF PETROLEUM, PARAFFIN OIL, AND OZOKERITE AND PARAFFIN WAX IMPORTED FOR CONSUMPTION INTO THE UNITED STATES, 1910–1914

Year	Petroleum		Paraffin oil		Ozokerite and paraffin wax		Total value
	Quantity	Value	Quantity	Value	Quantity	Value	
	Barrels		Barrels		Pounds		
1910	557,181	$1,398,861	2,952	$39,748	15,971,672	$986,081	$2,424,690
1911	1,709,932	2,410,884	4,019	43,343	12,699,459	749,475	3,203,702
1912	7,383,229	6,082,881	2,571	32,565	17,617,068	985,959	7,101,405
1913	17,809,058	12,947,280	3,676	49,458	16,051,322	932,894	13,929,632
1914	17,247,483	11,465,466	2,481	36,687	15,516,242	824,234	12,326,387

TABLE XXXV.—PRODUCTION OF PETROLEUM IN THE UNITED STATES.

Year	Pennsylvania and New York	Ohio	West Virginia	California	Kentucky and Tennessee	Colorado	Indiana	Illinois
1859	2,000	....	....	....	....	....	....	....
1860	500,000	....	....	....	....	....	....	....
1861	2,113,609	....	....	....	....	....	....	....
1862	3,056,690	....	....	....	....	....	....	....
1863	2,611,309	....	....	....	....	....	....	....
1864	2,116,109	....	....	....	....	....	....	....
1865	2,497,700	....	....	....	....	....	....	....
1866	3,597,700	....	....	....	....	....	....	....
1867	3,347,300	....	....	....	....	....	....	....
1868	3,646,117	....	....	....	....	....	....	....
1869	4,215,000	....	....	....	....	....	....	....
1870	5,260,745	....	....	....	....	....	....	....
1871	5,205,234	....	....	....	....	....	....	....
1872	6,293,194	....	....	....	....	....	....	....
1873	9,893,786	....	....	....	....	....	....	....
1874	10,926,945	....	....	....	....	....	....	....
1875	8,787,514	....	....	....	....	....	....	....
1876	8,968,906	31,763	120,000	12,000	....	....	....	....
1877	13,135,475	29,888	172,000	13,000	....	....	....	....
1878	15,163,462	38,179	180,000	15,227	....	....	....	....
1879	19,685,176	29,112	180,000	19,858	....	....	....	....
1880	26,027,631	38,940	179,000	40,552	....	....	....	....
1881	27,376,509	33,867	151,000	99,862	....	....	....	....
1882	30,053,500	39,761	128,000	128,636	....	....	....	....
1883	23,128,389	47,632	126,000	142,857	4,755	....	....	....
1884	23,772,209	90,081	90,000	262,000	4,148	....	....	....
1885	20,776,041	661,580	91,000	325,000	5,164	....	....	....
1886	25,798,000	1,782,970	102,000	377,145	4,726	....	....	....
1887	22,356,193	5,022,632	145,000	678,572	4,791	76,295	....	....
1888	16,488,668	10,010,868	119,448	690,333	5,096	297,612	....	....
1889	21;487,435	12,471,466	544,113	303,220	5,400	316,476	33,375	1,460
1890	28,458,208	16,124,656	492,578	307,360	6,000	368,842	63,496	900
1891	33,009,236	17,740,301	2,406,218	323,600	9,000	665,482	136,634	675
1892	28,422,377	16,362,921	3,810,086	385,049	6,500	824,000	698,068	521
1893	20,314,513	16,249,769	8,445,412	470,179	3,000	594,390	2,335,293	400
1894	19,019,990	16,792,154	8,577,624	705,969	1,500	515,746	3,688,666	300
1895	19,144,390	19,545,233	8,120,125	1,208,482	1,500	438,232	4,386,132	200
1896	20,584,421	23,941,169	10,019,770	1,252,777	1,680	361,450	4,680,732	250
1897	19,262,066	21,560,515	13,090,045	1,903,411	322	384,934	4,122,356	500
1898	15,948,464	18,738,708	13,615,101	2,257,207	5,568	444,383	3,730,907	360
1899	14,374,512	21,142,108	13,910,630	2,642,095	18,280	390,278	3,848,182	360
1900	14,559,127	22,362,730	16,195,675	4,324,484	62,259	317,385	4,874,392	200
1901	13,831,996	21,648,083	14,177,126	8,786,330	137,259	460,520	5,757,086	250
1902	13,183,610	21,014,231	13,513,345	13,984,268	185,331	396,901	7,480,896	200
1903	12,518,134	20,480,286	12,899,395	24,382,472	554,286	483,925	9,186,411	....
1904	12,239,026	18,876,631	12,644,686	29,649,434	998,284	501,763	11,339,124	....
1905	11,554,777	16,346,660	11,578,110	33,427,473	1,217,337	376,238	10,964,247	181,084
1906	11,500,410	14,787,763	10,120,935	33,098,598	1,213,548	327,582	7,673,477	4,397,050
1907	11,211,606	12,207,448	9,095,296	39,748,375	820,844	331,851	5,128,037	24,281,973
1908	10,584,453	10,858,797	9,523,176	44,854,737	f727,767	379,653	3,283,629	33,686,238
1909	10,434,300	10,632,793	10,745,092	55,471,601	f639,016	310,861	2,296,086	30,898,339
1910	9,848,500	9,916,370	11,753,071	73,010,560	f468,774	239,794	2,159,725	33,143,262
1911	9,200,673	8,817,112	9,795,464	81,134,391	f472,458	226,926	1,695,289	31,317,038
1912	8,712,076	a8,969,007	12,128,962	o87,272,593	f484,368	206,052	970,009	28,601,308
1913	8,865,493	8,781,468	11,567,299	97,788,525	f524,568	188,799	956,095	23,893,899
1914	9,109,309	8,536,352	9,680,033	99,775,327	502,441	222,773	1,335,456	21,919,749
Total	754,180,213	432,762,004	260,232,815	741,273,559	9,095,970	10,649,143	102,823,800	232,326,616

a Includes the production of Michigan.
b Includes the production of Oklahoma.
c Included with Kansas.
d Estimated.
e Includes production of Utah.
f No production in Tennessee recorded.

1859–1914, BY YEARS AND BY STATES, IN BARRELS OF 42 GAL.[1]

Kansas	Texas	Missouri	Oklahoma	Wyoming	Louisiana	United States	Total value	Year
...	...	...	...	...	...	2,000	$32,000	1859
...	...	...	...	...	...	500,000	4,800,000	1860
...	...	...	...	...	...	2,113,609	1,035,668	1861
...	...	...	...	...	...	3,056,690	3,209,525	1862
...	...	...	...	...	...	2,611,309	8,225,663	1863
...	...	...	...	...	...	2,116,109	20,896,576	1864
...	...	...	...	...	...	2,497,700	16,459,853	1865
...	...	...	...	...	...	3,597,700	13,455,398	1866
...	...	...	...	...	...	3,347,300	8,066,993	1867
...	...	...	...	...	...	3,646,117	13,217,174	1868
...	...	...	...	...	...	4,215,000	23,730,450	1869
...	...	...	...	...	...	5,260,745	20,503,754	1870
...	...	...	...	...	...	5,205,234	22,591,180	1871
...	...	...	...	...	...	6,293,194	21,440,503	1872
...	...	...	...	...	...	9,893,786	18,100,464	1873
...	...	...	...	...	...	10,926,945	12,647,527	1874
...	...	...	...	...	...	8,787,514	7,368,133	1875
...	...	...	...	...	...	9,132,669	22,982,822	1876
...	...	...	...	...	...	13,350,363	31,788,566	1877
...	...	...	...	...	...	15,396,868	18,044,520	1878
...	...	...	...	...	...	19,914,146	17,210,708	1879
...	...	...	...	...	...	26,286,123	24,600,638	1880
...	...	...	...	...	...	27,661,238	23,512,051	1881
...	...	...	...	...	...	30,349,897	23,631,165	1882
...	...	...	...	...	...	23,449,633	25,740,252	1883
...	...	...	...	...	...	24,218,438	20,476,924	1884
...	...	...	...	...	...	21,858,785	19,193,694	1885
...	...	...	...	...	...	28,064,841	20,028,457	1886
...	...	...	...	...	...	28,283,483	18,856,606	1887
...	...	...	...	...	...	27,612,025	17,950,353	1888
500	48	20	...	...	...	35,163,513	26,963,340	1889
1,200	54	278	...	...	...	45,823,572	35,365,105	1890
1,400	54	25	30	...	...	54,292,655	30,526,553	1891
5,000	45	10	80	...	...	50,514,657	25,906,463	1892
18,000	50	50	10	...	...	48,431,066	28,950,326	1893
40,000	60	8	130	2,369	...	49,344,516	35,522,095	1894
44,430	50	10	37	3,455	...	52,892,276	57,632,296	1895
113,571	1,450	43	170	2,878	...	60,960,361	58,518,709	1896
81,098	65,975	19	625	3,650	...	60,475,516	40,874,072	1897
71,980	546,070	10	...	5,475	...	55,364,233	44,193,359	1898
69,700	669,013	132	...	5,560	...	57,070,850	64,603,904	1899
74,714	836,039	*a*1,602	6,472	5,450	...	63,620,529	75,989,313	1900
179,151	4,393,658	*a*2,335	10,000	5,400	...	69,389,194	66,417,334	1901
331,749	18,083,658	*a*757	37,100	6,253	548,617	88,766,916	71,178,910	1902
932,214	17,955,572	*a*3,000	138,911	8,960	917,771	100,461,337	94,694,050	1903
4,250,779	22,241,413	*a*2,572	1,366,748	11,542	2,958,958	117,080,960	101,175,455	1904
*b*12,013,495	28,136,189	*a*3,100	*c*	8,454	8,910,416	134,717,580	84,157,399	1905
*b*21,718,648	12,567,897	*a*3,500	*c*	*d*7,000	9,077,528	126,493,936	92,444,735	1906
2,409,521	12,322,696	*a*4,000	43,524,128	*e*9,339	5,000,221	166,095,335	120,106,749	1907
1,801,781	11,206,464	*a*15,246	45,798,765	*e*17,775	5,788,874	178,527,355	129,079,184	1908
1,263,764	9,534,467	*a*6,750	47,859,218	*e*20,056	3,059,531	183,170,874	128,328,487	1909
1,128,668	8,899,266	*a*3,615	52,028,718	*e*115,430	6,841,395	209,557,248	127,899,688	1910
1,278,819	9,526,474	*a*7,995	56,069,637	*e*186,695	10,720,420	220,449,391	134,044,752	1911
1,592,796	11,735,057	*h*	51,427,071	1,572,306	9,263,439	222,935,044	164,213,247	1912
2,375,029	15,009,478	*i*10,843	63,579,384	2,406,522	12,498,828	248,446,230	237,121,388	1913
3,103,585	20,068,184	*j*7,792	73,631,724	3,560,375	14,309,435	265,762,535	214,125,215	1914
54,901,592	203,799,381	72,712	435,478,958	7,964,944	89,895,433	3,335,457,140	2,789,829,745	Total

g Includes small production of Alaska.
h No production in Missouri; Michigan included in Ohio.
i Includes production of Alaska, Michigan, and New Mexico.
j Includes production of Alaska and Michigan.
[1] *Mineral Resources of the United States*, **1913**, ii, 938–9; **1914**, ii, 898–9.

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TABLE XXXVI.—WORLD'S MARKETED PRODUCTION OF CRUDE PETROLE-

	Rumania	United States	Italy	Canada	Russia	Galicia	Japan and Formosa
1857	1,977	....	....	....	....	....	....
1858	3,560	....	....	....	....	....	....
1859	4,349	2,000	....	....	....	....	....
1860	8,542	500,000	36	....	....	....	....
1861	17,279	2,113,609	29	....	....	....	....
1862	23,198	3,056,690	29	11,775	....	....	....
1863	27,943	2,611,309	58	82,814	40,816	....	....
1864	33,013	2,116,109	72	90,000	64,586	....	....
1865	39,017	2,497,700	2,265	110,000	66,542	....	....
1866	42,534	3,597,700	992	175,000	83,052	....	....
1867	50,838	3,347,300	791	190,000	119,917	....	....
1868	55,369	3,646,117	367	200,000	88,327	....	....
1869	58,533	4,215,000	144	220,000	202,308	....	....
1870	83,765	5,260,745	86	250,000	204,618	....	....
1871	90,030	5,205,234	273	269,397	165,129	....	....
1872	91,251	6,293,194	331	308,100	184,391	....	....
1873	104,036	9,893,786	467	365,052	474,379	....	....
1874	103,177	10,926,945	604	168,807	583,751	149,837	....
1875	108,569	8,787,514	813	220,000	697,364	158,522	4,566
1876	111,314	9,132,669	2,891	312,000	1,320,528	164,157	7,708
1877	108,569	13,350,363	2,934	312,000	1,800,720	169,792	9,560
1878	109,300	15,396,868	4,329	312,000	2,400,960	175,420	17,884
1879	110,007	19,914,146	2,891	575,000	2,761,104	214,800	23,457
1880	114,321	26,286,123	2,035	350,000	3,001,200	229,120	25,497
1881	121,511	27,661,238	1,237	275,000	3,601,441	286,400	16,751
1882	136,610	30,349,897	1,316	275,000	4,537,815	330,076	15,549
1883	139,486	23,449,633	1,618	250,000	6,002,401	365,160	20,473
1884	210,667	24,218,438	2,855	250,000	10,804,577	408,120	27,923
1885	193,411	21,858,785	1,941	250,000	13,924,596	465,400	29,237
1886	168,606	28,064,841	1,575	584,061	18,006,407	305,884	37,916
1887	181,907	28,283,483	1,496	525,655	18,367,781	343,832	28,645
1888	218,576	27,612,025	1,251	695,203	23,048,787	466,537	37,436
1889	297,666	35,163,513	1,273	704,690	24,609,407	515,268	52,811
1890	383,227	45,823,572	2,998	795,030	28,691,218	659,012	51,420
1891	488,201	54,292,655	8,305	755,298	34,573,181	630,730	52,917
1892	593,175	50,514,657	18,321	779,753	35,774,504	646,220	68,901
1893	535,655	48,431,066	19,069	798,406	40,456,519	692,669	106,384
1894	507,255	49,344,516	20,552	829,104	36,375,428	949,146	171,744
1895	575,200	52,892,276	25,843	726,138	46,140,174	1,452,999	141,310
1896	543,348	60,960,361	18,149	726,822	47,220,633	2,443,080	197,082
1897	570,886	60,475,516	13,892	709,857	54,399,568	2,226,368	218,559
1898	776,238	55,364,233	14,489	758,391	61,609,357	2,376,108	265,389
1899	1,425,777	57,070,850	16,121	808,570	65,954,968	2,313,047	536,079
1900	1,628,535	63,620,529	12,102	913,498	75,779,417	2,346,505	866,814
1901	1,678,320	69,389,194	16,150	756,679	85,168,556	3,251,544	1,110,790
1902	2,059,935	88,766,916	18,933	530,624	80,540,044	4,142,159	1,193,038
1903	2,763,117	100,461,337	17,876	486,637	75,591,256	5,234,475	1,209,371
1904	3,599,026	117,080,960	25,476	552,575	78,536,655	5,947,383	1,419,473
1905	4,420,987	134,717,580	44,027	634,095	54,960,270	5,765,317	1,472,804
1906	6,378,184	126,493,936	53,577	569,753	58,897,311	5,467,967	1,710,768
1907	8,118,207	166,095,335	59,875	788,872	61,850,734	8,455,841	2,001,838
1908	8,252,157	178,527,355	50,966	527,987	62,186,447	12,612,295	2,070,145
1909	9,327,278	183,170,874	42,388	420,755	65,970,350	14,932,799	1,889,563
1910	9,723,806	209,557,248	50,830	315,895	70,336,574	12,673,688	1,930,661
1911	11,107,450	220,449,391	74,709	291,096	66,183,691	10,519,270	1,658,903
1912	12,976,232	222,935,044	53,778	243,336	68,019,208	8,535,174	1,671,405
1913	13,554,768	248,446,230	47,256	228,080	62,834,356	7,818,130	1,942,009
1914	12,826,579	265,762,535	a39,548	214,805	67,020,522	a5,033,350	2,738,378
Total	117,982,474	3,335,457,140	802,229	23,493,610	1,622,233,845	131,873,601	27,051,158

a Estimated.

UM, 1857–1914, BY YEARS AND BY COUNTRIES, IN BARRELS OF 42 GAL.

	Germany	India	Dutch East Indies	Peru	Mexico	Other countries	Total
1857							1,977
1858							3,560
1859							6,349
1860							508,578
1861							2,130,917
1862							3,091,692
1863							2,762,940
1864							2,303,780
1865							2,715,524
1866							3,899,278
1867							3,708,846
1868							3,990,180
1869							4,695,985
1870							5,799,214
1871							5,730,063
1872							6,877,267
1873							10,837,720
1874							11,933,121
1875							9,977,348
1876							11,051,267
1877							15,753,938
1878							18,416,761
1879							23,601,405
1880	9,310						30,017,606
1881	29,219						31,992,797
1882	58,025						35,704,288
1883	26,708						30,255,479
1884	46,161						35,968,741
1885	41,360						36,764,730
1886	73,864						47,243,154
1887	74,284						47,807,083
1888	84,782						52,164,597
1889	68,217	94,250					61,507,095
1890	108,296	118,065					76,632,838
1891	108,929	190,131					91,100,347
1892	101,404	242,284					88,739,219
1893	99,390	298,969	600,000				92,038,127
1894	122,564	327,218	688,170				89,335,697
1895	121,277	371,536	1,215,757				103,662,510
1896	145,061	429,979	1,427,132	47,536			114,159,183
1897	165,745	545,704	2,551,649	70,831			121,948,575
1898	183,427	542,110	2,964,035	70,905			124,924,682
1899	192,232	940,971	1,795,961	89,166			131,143,742
1900	358,297	1,078,264	2,253,355	274,800			149,132,116
1901	313,630	1,330,716	4,013,710	274,800			167,424,089
1902	353,674	1,617,363	2,430,465	286,725			181,965,876
1903	445,818	2,510,259	5,770,056	278,092			194,804,294
1904	637,431	3,385,468	6,508,485	345,834	220,653		218,299,419
1905	560,963	4,137,098	7,849,896	447,880	320,379		215,361,296
1906	578,610	4,015,803	8,180,657	536,294	1,097,264		214,010,124
1907	756,631	4,344,162	9,982,597	756,226	1,717,690		264,958,008
1908	1,009,278	5,047,038	10,283,357	1,011,180	3,481,610		285,089,984
1909	1,018,837	6,676,517	11,041,852	1,316,118	2,488,742		298,373,216
1910	1,032,522	6,137,990	11,030,620	1,330,105	3,332,807		327,615,603
1911	1,017,045	6,451,203	12,172,949	1,368,274	14,051,643		345,685,081
1912	1,031,050	7,116,672	10,845,624	1,751,143	16,558,215		352,484,591
1913	a995,764	7,930,149	11,966,857	2,133,261	29,902,439		384,667,505
1914	a995,764	a8,000,000	b12,705,208	1,917,802	21,188,427		400,483,489
Total	12,965,569	73,979,919	138,278,392	14,306,972	90,359,869	4,478,158c	5,593,262,936

a Estimated.
b Includes British Borneo.
c From 1901–1914. Includes Trinidad, Egypt, and Argentina (600,000 bbl. in 1914).

The Standard Oil Company.[1]—In 1870, John D. and William Rockefeller, Samuel Adams, Henry M. Flagler, and Stephen V. Harkness, and the firms of William Rockefeller and Company, Rockefeller and Andrews, and Rockefeller and Company, consolidated their businesses of refining, shipping and selling petroleum, in the State of Ohio and other states, as the Standard Oil Company, an Ohio corporation with a capital of $1,000,000.[2] This capital was increased on Feb. 10, 1872, to $2,500,000 and on Mar. 13, 1873, to $3,500,000. In 1873, practically all of the petroleum refineries in Cleveland, Ohio, were acquired; and subsequently, by the purchase of properties or stocks and by trade agreements, the Standard Oil Company or its organizers secured, in 1882, control of a very large proportion of the business of purchasing, shipping, refining, and selling petroleum and its products in the United States.

On Jan. 2, 1882, a trust agreement, with a supplemental agreement on Jan. 4, 1882, was entered into, providing for the incorporation in each of several states of a company entitled the "Standard Oil Company" of such state, to each of which were to be transferred the properties in its own state. The trust certificates were issuable for the appraised value of the properties conveyed. Under the terms of this agreement, the Standard Oil Company of New Jersey was incorporated on Aug. 5, 1882,

[1] SEE MONTAGUE'S "Rise and Progress of the Standard Oil Company," **1903**; TARBELL'S "History of the Standard Oil Company," **1911**; POOR'S "Manual of Industrials," **1913**, 1615; and "The Manual of Statistics," **1915**, 781.

On the important part played by the Standard Oil Company in the early development of the American petroleum industry, see S. C. T. DODD'S "Combinations: their Uses and Abuses; with a History of the Standard Oil Trust," New York, **1888**.

[2] The purposes of this alliance were to cheapen transportation, both local and to the seaboard; to manufacture a better grade of illuminating oil at less expense by uniting the knowledge, experience and skill of all parties, as well as their various secret processes and patents; to unite with the business of refining the business necessarily collateral thereto (manufacture of barrels, tin cans, boxes, paint, glue, and sulphuric acid); to obtain and utilize the best scientific skill in investigating and experimenting upon the obtaining of new and useful products from petroleum, and to cheapen illuminating oils by obtaining profits from the by-products; to employ agents and send them through the world to open up markets; and by all the means enumerated to increase the supply of petroleum products and lessen their price to the consumer.

with a capital stock of $3,000,000, increased from time to time, up to 1889, to $10,000,000. In 1892, the Standard Oil Trust was obliged to liquidate. It became a "trust in liquidation," and there it remained for some five years. In 1898, however, it was found that the corporation law of the State of New Jersey offered a refuge, and here it settled. Accordingly, the Standard Oil Company of New Jersey was reincorporated on June 14, 1899, under the laws of New Jersey, increasing the capital stock from $10,000,000 to $100,000,000 common and $10,000,000 preferred,[1] for the purpose of purchasing the stocks of various companies formerly held by the liquidating trustees of the Standard Oil Trust.

On Nov. 15, 1906, the Attorney General of the United States brought suit for the dissolution of the Standard Oil Company of New Jersey in the United States Court at St. Louis, Mo. Pursuant to the decision of the United States Circuit Court at St. Louis on Nov. 20, 1909, which was affirmed by the United States Supreme Court on May 15, 1911, ordering the dissolution of the Company,[2] the stocks of the 33 subsidiary companies were distributed to the shareholders.

The Standard Oil Group.—The several companies formerly controlled by the Standard Oil Company of New Jersey, and commonly referred to as "Standard Oil Companies," are generally classed together as the "Standard Oil Group."[3] Facts of interest relating to the companies comprising this group, are presented in the following table.

[1] This was later retired and common stock issued therefor.

[2] The Company was found to be a combination in restraint of trade and commerce, and six months were allowed for the return to its component parts. This decision is notable for its emphasis of the rule of reason in dealing with cases subject to the Sherman Antitrust Law of July 2, 1890.

[3] Moody's "Manual of Railroads and Corporation Securities," **1915**, 3331; and Poor's "Manual of Industrials," **1915**, 1556.

Company	Date of incorporation	Where incorporated	Capital stock	Business
Anglo-American Oil Co., Ltd.	1888	England	£2,000,000	Engaged in marketing petroleum products in England.
Atlantic Refining Co.	Apr. 29, 1870	Pennsylvania	$5,000,000	Operates refineries at Philadelphia, Pittsburgh and Franklin, Pa.; and maintains distributing stations in all cities and large towns in Pennsylvania and Delaware.
Borne, Scrymser Co.	Mar. 15, 1893	New Jersey	$200,000	Business is confined to lubricating oils and greases. Plant is located at Claremont, Jersey City, N. J.
The Buckeye Pipe Line Co.	Mar. 31, 1886	Ohio	$10,000,000	Owns 575 miles of pipe lines in Ohio and West Virginia.
The Chesebrough Manufacturing Co.	May 10, 1880	New York	$500,000	Sole manufacturer of vaseline and its preparations. Plant is located at Perth Amboy, N. J. Owns deposits of fuller's earth in Florida.
Colonial Oil Co.	1901	New Jersey	$250,000	Was formerly engaged in marketing the Standard products in South Africa and Australia; since 1906, this business has been transferred to the Vacuum Oil Co. Has a marketing station at Buenos Ayres.
The Continental Oil Co.	1913	Colorado	$3,000,000	Successor to the Continental Oil Co. of Iowa. Conducts a marketing business in Colorado, Wyoming, Idaho, New Mexico, Utah, and Montana. Its products are obtained from refineries at Florence, Colo., and Casper, Wyo.
The Crescent Pipe Line Co.	1891	Pennsylvania	$3,000,000	Owns and operates 269 miles of 5- and 6-in. pipe line running from Greggs, Pa., to Marcus Hook, near Philadelphia, Pa.
Cumberland Pipe Line Co., Inc.	Nov. 15, 1901	Kentucky	$1,000,000	Owns 467 miles of pipe line of various sizes, from 2-in. to 6-in., of which the main lines embrace 51 miles of 6-in. and 154 miles of 4-in. pipe, extending from Monticello Station *via* Somerset and Licking River Junction to Clifford on Tug Fork, connecting at that point with the Eureka Pipe Line Co., and from Page Hollow *via* Lewis to Licking River Junction.

Company	Date of incorporation	Where incorporated	Capital stock	Business
The Eureka Pipe Line Co.	1890	West Virginia	$5,000,000	Owns 4,216 miles of pipe line reaching nearly all of the wells in West Virginia. In addition to gathering oil from these wells, the trunk lines of the company are engaged in interstate handling of oil.
Galena-Signal Oil Co.	Nov. 7, 1901	Pennsylvania	$14,000,000	Manufactures lubricating and signal oils (annual output is 800,000 bbl.). Plants at Franklin, Pa.; Toronto, Canada; Parkersburg, W. Va.; Boston, Mass.; Rouen, France; and Bayonne, N. J.
Indiana Pipe Line Co.	1889	Indiana	$5,000,000	Owns and operates over 450 miles of pipe lines.
National Transit Co.	Apr. 30, 1881	Pennsylvania	$12,727,575	Owns pipe lines in Pennsylvania, a network of feeding pipes and storage tanks in western Pennsylvania, and shops and three office buildings in Oil City, Pa. The company's trunk lines connect with those of the Buckeye Pipe Line Co., and the New York Transit Co., which supplies the Vacuum Oil Co., the Atlantic Refining Co., and other refineries, and also connects with the lines of the Standard Oil Co. of New Jersey.
New York Transit Co.	Jan. 18, 1892	New York	$5,000,000	Owns and operates approximately 200 miles of trunk pipe lines, extending from Olean, N. Y., to and connecting with the Standard Refineries of the Standard Oil Co. of N. J., at Bayonne, N. J. and the Long Island City plant of the Standard Oil Co. of New York. It also operates a branch line from Olean to Buffalo, N. Y. In addition to its extensive pipe lines, it owns about one-third of the tankage facilities at Olean, N. Y.
Northern Pipe Line Co.	July 8, 1889	Pennsylvania	$4,000,000	Owns and operates a pipe line in the northern part of Pennsylvania. The system comprises over 200 miles of trunk pipe lines, extending from the western border of Pennsylvania to Bear Creek, Clarion Co., to Colebrook, McKean Co., where connections are made with the eastern branch of the National Transit Co.

Company	Date of incorporation	Where incorporated	Capital stock	Business
The Ohio Oil Co.	1887	Ohio	$15,000,000	A producing and pipe line Company, owning wells in Illinois and Ohio, with a gathering system of pipes and a trunk line from the Illinois fields across Indiana, Ohio, and Pennsylvania.
The Illinois Pipe Line Co.	Nov. 27, 1914	Ohio	$20,000,000	Took over The Ohio Oil Company's trunk and gathering pipe line systems in Illinois, Ohio, and Pennsylvania.
Pierce Oil Corporation	1913	Virginia	$30,000,000	Acquired properties of the Waters-Pierce Oil Co., which distributed and sold petroleum products in Missouri, Illinois, Arkansas, Oklahoma, Louisiana, and Texas, and, since 1877, refined and sold products in Mexico.
Prairie Oil and Gas Co.	Dec. 15, 1900	Kansas	$20,000,000	Owns producing properties in Kansas and Oklahoma.
Prairie Pipe Line Co.	Jan. 14, 1915	Kansas	$27,000,000	This Company took over the transportation business of the Prairie Oil and Gas Co.
Solar Refining Co.	1886	Ohio	$2,000,000	Owns a refinery covering 280 acres at Lima, Ohio; the annual capacity of this refinery is about 3,650,000 bbl.
Southern Pipe Line Co.	1890	Pennsylvania	$10,000,000	This Company has 1,130 miles of pipe line in Pennsylvania.
South Penn Oil Co.	1889	Pennsylvania	$12,500,000	Producer of crude petroleum in the Appalachian field. In 1913, this Company acquired control of the Penn-Mex Fuel Co.
South West Pennsylvania Pipe Line	1886	Pennsylvania	$3,500,000	This Company has 1,646 miles of pipe line in Pennsylvania.
Standard Oil Co. (California)	Sept. 10, 1879	California	$100,000,000	Incorporated as Pacific Coast Oil Co. Name changed to Standard Oil Co. on June 23, 1906. Refineries at Point Richmond, El Segundo, and Bakersfield, Cal. (see also p. 509).
Standard Oil Co. (Indiana)	June 18, 1880	Indiana	$30,000,000	Owns refineries at Whiting, Ind. (30,000 to 35,000 bbl. per day of Oklahoma crude), at Wood River, Ill. (Illinois crude), at Sugar Creek, Mo. (10,000 to 15,000 bbl. of Oklahoma crude per day), and at Casper, Wyo. ($1,000,000 plant).

Company	Date of incorporation	Where incorporated	Capital stock	Business
Standard Oil Co. (Kansas)	Dec. 24, 1892	Kansas	$2,000,000	Owns a refinery at Neodesha, Kan., which has a daily capacity of 7,500 bbl.
Standard Oil Co. (Kentucky)	Oct. 7, 1886	Kentucky	$3,000,000	A marketing Company having stations in Alabama, Florida, Georgia, Kentucky, and Mississippi.
Standard Oil Co. (Nebraska)	1906	Nebraska	$1,000,000	A marketing Company with 151 agencies in Nebraska.
Standard Oil Co. of New Jersey	Aug. 5, 1882	New Jersey	$100,000,000	This Company now owns and operates refineries at Bayonne, Bayway, Parkersburg, Baltimore, and Sarnia, Ontario. These refineries have a combined daily capacity of about 100,000 bbl.
International Petroleum Co., Ltd.	Sept. 10, 1914	England	£4,000,000	This Company acquired control of the London and Pacific Oil Co., Ltd., the West Coast Oil Fuel Co., and the Lagunitas Oil Co., Ltd.—all operating in the Peruvian oil fields.
Standard Oil Co. of New York	Aug. 10, 1882	New York	$75,000,000	This Company owns the Pratt Works, Long Island Works, and the Stone and Fleming Works in New York, and the Atlas Works in Buffalo. These plants have a combined capacity of 20,000 bbl. per day.
Standard Oil Co. of Ohio	Jan. 10, 1870	Ohio	$3,500,000	This Company has two refineries in Cleveland and marketing stations through Ohio.
Swan and Finch Co.	1891	New York	$500,000	Engaged in the compounding of lubricants, mainly for the use of railroads.
Union Tank Line Co.	1891	New Jersey	$12,000,000	Owns 13,500 tank cars, which it leases to shippers for the transportation of oils.
Vacuum Oil Co.	1866	New York	$15,000,000	This Company has a refinery at Olean, N. Y., and finishing and compounding plants at Bayonne, N. J., and Rochester, N. Y. It manufactures lubricating oils.
Washington Oil Co.	1887	Pennsylvania	$100,000	Produces crude petroleum. Property consists of 4,897 acres of leaseholds, 350 acres of oil rights, 250 acres of land owned in fee, 148 oil wells, and two gas wells.

Other Large Petroleum Companies.—The following list gives data relating to a number of the more prominent of the so-called "independent oil companies," which are outside of what is known as the "Standard Oil Group."

Company	Date of incorporation	Where incorporated	Capital stock	Business
American Oilfields Co.	Jan. 17, 1910	California	$25,000,000	Owns the entire capital stock of the Midland Oilfields Co., Ltd., and of the Midland Oil Co., and one-half of the capital stock of the Barnodon Oil Co. Either directly or through these subsidiary companies, the Company claims 13,000 acres of land in the Sunset, Midway, McKittrick and Lost Hills oil fields of California. It has established oil camps at different points and has constructed 11 steel storage tanks of 50,000 bbl. capacity each; also two reinforced concrete reservoirs having an aggregate capacity of 1,062,000 bbl. The Company has in operation upon one of its properties a complete topping plant (refinery) capable of topping 10,000 bbl. of oil daily.
American Petroleum Co.	Feb. 17, 1908	California	$15,000,000	Owns and controls about 2,000 acres of Coalinga, Lost Hills and Los Angeles oil fields of California. Has 97 wells, produces about 5,200 bbl. daily, and owns 6 steel tanks of 280,000 bbl. aggregate capacity and 11 iron tanks of 14,000 bbl. aggregate capacity. Owns $899,996 of the $1,000,000 outstanding capital stock of Niles Lease Co., which Company operates, under 20-year lease, 80 acres of land at Sherman, Cal.
Associated Oil Co.	Oct. 7, 1901	California	$40,000,000	Conducts a general business in the acquiring of properties, producing, manufacturing, refining and transporting oil in California and throughout the United States and Territories. The Company owns in fee 36,511 acres, leases 2,125 acres, and holds mineral locations on 3,200 acres, in and adjacent to various producing fields in California. Also owns and operates two refineries; one located at Gaviota, near Santa Barbara, the other at Avon, on the San Francisco Bay. Gasoline, distillates, kerosenes, lubricating and fuel oils are marketed through the

Company	Date of incorporation	Where incorporated	Capital stock	Business
Associated Oil Co.—*Cont.*				Company's own distributing plants, maintained at all important points in California, and at Portland, Ore.; Everett, Wash.; Nome, Alaska; Honolulu, Hawaii; and through selling agencies in Arizona, Nevada, and Utah. The Company owns pipe lines running from the Santa Maria oil fields to its refinery at Gaviota and from the Coalinga field to Monterey Bay. Also owns one-half interest in two pipe lines running from the various fields in the San Joaquin Valley to Port Costa on the San Francisco Bay. Owns rolling stock and vessels equipped for transporting both crude and refined oil.
California Oil Corporation	Sept. 27, 1912	Virginia	$35,000,000	Incorporated as a holding company, to hold and deal in securities of other corporations, and in addition to carry on the petroleum business in all its branches. At present the Company controls the American Oilfields Co. and the American Petroleum Co.
Gulf Oil Corporation	Feb. 14, 1907	New Jersey	Authorised, $60,000,000; outstanding, $33,800,600	Incorporated to acquire the securities of the J. M. Guffey Petroleum Co. and the Gulf Refining Co., and to construct a pipe line from Oklahoma to the Gulf of Mexico (Gulf Pipe Line Co. and Gulf Pipe Line Co. of Oklahoma). The Gulf Oil Corporation controls the Gulf Refining Co., through the ownership of 299,993 shares of its capital stock; also controls, through the ownership of a majority of their capital stocks, the following companies: The Gulf Pipe Line Co. (of Texas); Gulf Pipe Line Co. of Oklahoma; Gulf Refining Co. of Louisiana; the Gypsy Oil Co., and the Gulf Production Co. The Gulf Pipe Line Co. was incorporated on Nov. 30, 1906, in Texas; its capital stock is $3,500,000. It was incorporated for the transportation of oil and owns a pipe line in Texas. The Gulf Pipe Line Co. of Oklahoma was incorporated on Sept. 21, 1909, in Oklahoma; its capital stock is $1,000,000. It was incorporated for the transportation of oil and owns pipe lines in Oklahoma. The Gulf Re-

Company	Date of incorporation	Where incorporated	Capital stock	Business
Gulf Oil Corporation.—*Cont.*				fining Co. was incorporated on Nov. 26, 1901, in Texas; its capital stock, outstanding, is $7,500,000. It owns two refineries. The Gulf Refining Co. of Louisiana was incorporated on Dec. 22, 1905, in Louisiana; its capital stock, authorized and outstanding, is $1,000,000. It was incorporated for the purposes of producing and selling petroleum products; its properties are located in Louisiana. The Gypsy Oil Co. was incorporated on May 22, 1907, in Oklahoma; its capital stock, authorized and outstanding, is $500,000. It was incorporated for producing petroleum oils; its properties in Oklahoma have an annual production of 4,200,000 bbl. The J. M. Guffey Petroleum Co. changed its name to the Gulf Production Co. in 1915.
Indian Refining Co.	Nov., 1904	Maine	Preferred, $3,000,000; common, $4,500,000	Produces and refines crude oil and manufactures all products of petroleum. Controls Indian Refining Co. of New York, Bridgeport Oil Co., Havoline Oil Co., Record Oil Refining Co., and Indian Refining Co. of Oklahoma. Refineries at Lawrenceville, Ill., Georgetown, Ky., and New Orleans, La. Company also controls large storage stations at New Orleans, La., and Cairo, Ill., and has distributing stations in about 150 cities, chiefly east of Mississippi River. Also owns leased oil lands. Operates 1,020 tank cars.
Interocean Oil Co.	Dec., 1912	South Dakota	Authorized, $12,000,000 common; $2,000,000 7 per cent. cumulative first preferred, and $4,000,000 6 per cent. non-cumulative second preferred	Business consists of the refining and selling of crude mineral oil and its products. Plants at East Brooklyn, and Baltimore, Md., Carteret, N. J., Chester, Pa., Tampico, Mexico. Controls following companies: United Asphalt Refining Co., Interocean Transport Co., Toltec Mexican Oil Co., Aztec Asphalt Co., and Eastern Paving Co.

Company	Date of incorporation	Where incorporated	Capital stock	Business
The Midwest Refining Co.	Feb., 1914	Maine	Capital stock authorized, \$20,000,000	Incorporated for the purposes of conducting the general business of refining and marketing oil. The Company is engaged in this business at Casper, Wyo., and is the owner of the refining plants formerly owned by the Midwest Oil Co.
The National Refining Co.	July 6, 1906	Ohio	Authorized, \$5,000,000 8 per cent. cumulative preferred; \$5,000,000 common; outstanding preferred, \$4,012,500; common, \$3,877,400	Incorporated successors to a Delaware company of the same name, incorporated in 1901, which itself succeeded an Ohio company of the same name, incorporated in 1882. Works at Cleveland, Findlay and Marietta, Ohio, and Coffeyville, Kan. Refiners of petroleum and its products. This Company is associated with the Northern Oil Co., producers of crude oil, the National Pipe Line Co., transporters of oil, and Peerless Transit Line, carriers of oil. The National Refining Co. controls the Canada Oil Companies.
Shell Co. of California, Inc.	Aug. 30, 1912	New York	Authorized, \$4,000,000; outstanding; \$600,000	Plants located in California, Oregon, Washington, and British Columbia. Refines and sells petroleum, etc. The Valley Pipe Line Co., a subsidiary, in April, 1915, also constructed a pipe line in California. The Company is a subsidiary of the Royal Dutch Oil Co. and the Shell Transporting and Trading Co. of The Hague and London.
Texas Co.	Apr. 7, 1902	Texas	\$30,000,000	Engaged in the transportation, manufacture, purchase, and sale of petroleum and its products. Operates refineries, pipe lines, tank cars and tank steamers. It owns over 1,400 miles of pipe line reaching Texas, Oklahoma and Louisiana oil fields, extending from Tulsa, Oklahoma, to Port Arthur, Texas, *via* Dallas and Houston; also from Shreveport to Port Arthur and Saterals. The Company has erected and owns over 3,800 miles of telephone and telegraph lines connected with its various properties. It has a tankage of approximately 26,000,000 bbl. capacity. It owns one refinery at Port Arthur, Tex.; one at Port Neches, Tex.; one at Dallas, Tex.; one at Tulsa, Okla. and another at Lockport, Ill. These refineries have an aggregate daily capacity of 40,000 bbl.

Company	Date of incorporation	Where incorporated	Capital stock	Business
Texas Co.—*Cont.*				During the year ended June 30, 1914, the production handled by the different pipe lines exceeded 2,500,000 bbl. a month.
Tide Water Oil Co.	Nov. 17, 1888	New Jersey	$25,000,000	The business of this Company is refining petroleum; it has a refinery at Bayonne, N. J., with a capacity of 10,000 bbl. per day.
United Petroleum Co.	Jan. 25, 1899	California	$10,000,000	Incorporated as a holding company. The Company's principal income is derived through its holdings in the Union Provident Co., which Company it controls, and which in turn holds a majority of the outstanding stock of the Union Oil Co. of California. The United Provident Co. has an authorised capital stock of $25,000,000, of which $15,598,171 has been issued. The United Petroleum Co. of California was incorporated on Oct. 17, 1890, to produce and refine petroleums; its authorised capital stock is $50,000,000.

The National Petroleum Association.—The genesis of the National Petroleum Association, including in its membership nearly all the refiners of petroleum[1] (outside of what is known as

[1] The present members are as follows: American Oil Works, Ltd., Titusville, Pa.; The Bessemer Refining Co., Titusville, Pa.; Canfield Oil Co., Cleveland, Ohio; Central Refining Co., Lawrenceville, Ill.; The Chanute Refining Co., Chanute, Kan.; The F. G. Clark Co., Cleveland, Ohio; The Conewango Refining Co., Warren, Pa.; Consumers Refining Co., Chicago, Ill.; The Continental Refining Co., Oil City, Pa.; Cornplanter Refining Co., Warren, Pa.; Cosden & Co., Tulsa, Okla.; Crew Levick Co., Philadelphia, Pa.; Crystal Oil Works, Oil City, Pa.; Cudahy Refining Co., Chicago, Ill.; Emery Mfg. Co., Bradford, Pa.; Emlenton Refining Co., Emlenton, Pa.; Empire Oil Works, Oil City, Pa.; Germania Refining Co., Oil City, Pa.; Glade Oil Works, Warren, Pa.; The Great Western Oil Co., Cleveland, Ohio; Great Western Oil Refg. Co., Erie, Kan.; Gulf Refining Co., Pittsburgh, Pa.; Independent Refining Co., Ltd., Oil City, Pa.; The Island Petroleum Co., Pittsburgh, Pa.; The Kansas Co-Operative Refg. Co., Chanute, Kan.; The Kansas Oil Refining Co., Coffeyville, Kan.; Kendall Refining Co., Bradford, Pa.; Levi Smith, Ltd., North Clarendon, Pa.; Milliken Refining Co., St. Louis, Mo.; Mutual Refining Co., Ltd., Warren, Pa.; The National Refining Co., Cleveland, Ohio; The Paragon Refining Co., Toledo, Ohio; Pennsylvania Paraffine Works, Titusville, Pa.; Pitts-

the "Standard Oil Group") in the states of New York, Pennsylvania, Ohio and Illinois, and some in Kansas and Oklahoma, arose from the "necessity of mutual aid to avoid extermination" in 1902.

The association began with a membership of 17 independent refiners of Pennsylvania crude petroleum, located in the states of New York, Pennsylvania and Ohio. It was first organized as a voluntary association and held its first meeting for organizing in Pittsburgh, Pa., on June 17, 1902. At this meeting a constitution and by-laws were adopted, the preamble of the constitution being as follows:

"In order to create a permanent, social and coöperative feeling between refiners of petroleum and its products throughout the United States, to remove by concerted action any evils and customs that are against good policy and sound business principles, to correct existing abuses and to secure the enactment of wise and uniform state inspection laws, the operation of which may be equally fair to all and which may accomplish the ends designed, and to prevent unjust discrimination, and that all grievances may be fairly and equitably adjusted, we form ourselves into an association to be known as The National Petroleum Association."

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burgh Oil Refining Co., Coraopolis, Pa.; The Red "C" Oil Mfg. Co., Baltimore, Md.; Seneca Oil Works, Warren, Pa.; Superior Oil Works, Warren, Pa.; Tiona Refining Co., North Clarendon, Pa.; Union Petroleum Co., Philadelphia, Pa.; United Refining Co., Warren, Pa.; Waverly Oil Works Co., Pittsburgh, Pa.; Warren Refining Co., Warren, Pa.; Wellsville Refining Co., Wellsville, N. Y.; Indian Refining Co., New York; and Petroleum Products Co., Chicago, Ill.

CHAPTER VI

OIL WELL TECHNOLOGY

A General Description of the Operation of Drilling.—As an introduction to what follows in this chapter, it is appropriate to present a descriptive account of the operation of drilling, according to what may be referred to as the Pennsylvanian practice.

The first operation in the drilling of an oil well consists in sinking a "conductor" down to the "bed-rock." An ordinary shaft, about 8 or 10 ft. square, is dug to the "bed-rock," when this lies at a depth of not more than 10 or 15 ft., and a wooden "conductor," of somewhat greater internal diameter than the maximum bore of the well, is then placed so as to extend from the floor of the derrick to the "bed-rock," the junction with the latter being very carefully made, in order to prevent the entrance of gravel and mud into the well.

In cases where the superficial deposit is too thick to admit of digging to the rock, a strong iron "drive-pipe," furnished at the lower end with a sharp steel shoe, is driven down, as in pile driving. This is, however, an operation which requires considerable skill, since it is difficult to maintain the vertical position of the pipe, especially when the depth extends to 200 to 300 ft. When the rock is less than about 60 ft. from the surface, the drilling tools cannot at first be worked in the usual manner, and the operation of drilling is commenced by "spudding." For this purpose the drilling tools are raised and dropped by tightening and then slackening the cable, which is coiled either two or three times round the axle of the revolving bull wheel, the end being held by the driller, so that, by loosening it, he can let the drill drop, or, by tightening it, can cause the tools to be raised; or the cable is attached to the crank of the band wheel by a "jerk rope."[1]

The further operation of drilling, as practised in Pennsylvania, is, in general, as follows:

When a sufficient depth has been reached by spudding to admit

[1] See Figs. 59 and 60 in the following section on *Drilling Methods and Appliances.*

of the introduction of a full "string of tools," the spudding machinery is abandoned. "Now," to quote Carll,[1]

"the coil of drilling cable is rolled into the derrick, and set upon end. The free end in the center of the coil is tied by a connecting cord to the rope just detached from the ring socket, and by it drawn up over the crown pulley and down to the bull-wheel shaft, where it is fastened; the bull rope is put in place, the engine started, and the men carefully watch and guide the cable as it is wound, coil after coil, smoothly and solidly upon the shaft. When this is done, the end of the cable depending from the crown pulley is secured to the rope socket, and the full set of tools is attacheds and wung up in the derrick. After carefully screwing up all the joints (the bull rope having been unshipped), the tools are lowered into the hole by means of the bull-wheel brake. The band-wheel crank is then turned to the upper center; the pitman is raised and slipped upon the wrist pin, where it is secured by the key and wedges; the temper screw is hung upon the walking beam, instead of from the top of the derrick as before. Some 15 to 20 ft. of slack cable should be pulled down and thrown upon the floor, to give free movement to the drill. When the drill is rotated in one direction for some time, the slack coils around the cable at the well mouth; if it becomes troublesome, the motion is reversed, and it uncoils. Only by this constant rotation of the drill can a round hole be ensured.

"Having now made all the necessary connections, it only remains to give the engine steam, and the drill will rise and fall with each revolution of the band wheel, and commence its aggressive work upon the rock below. From this point downward, the daily routine of the work is very monotonous, unless some accident occurs to diversify it. Day and night the machinery is kept in motion. One driller and one engineer and tool dresser work from noon until midnight (the 'afternoon tour'), and another pair from midnight until noon (the 'morning tour'). Up and down goes the walking-beam, while the driller, with a short lever inserted in the rings of the temper-screw, walks round and round, first this way, then that, to rotate the drill. He watches the jar, and, at proper intervals, lets down the temper screw as the drill penetrates the rock. When the whole length of the screw has been 'run out,' or the slow progress of the drill gives warning that it is working in hard rock and needs sharpening, he arranges the slack cable upon the floor, so that it will go up freely without kinks, and informs the engineer that he is ready to 'draw out.' After attending to the needful preliminaries, the driller throws the bull rope upon its pulley, and quickly steps to the bull-wheel brake, while the engineer commands the throttle of the engine. The walking beam and the bull wheel are now both in

[1] Carll, "The Geology of the Oil Regions of Warren, Venango, Clarion and Butler Counties," 306.

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motion, but, at the proper moment, one man stops the engine and the other holds the bull wheels with the brake just when all the slack cable has been taken up, and the weight of the tools is thus transferred from the temper screw to the crown pulley. This is a performance requiring experience and good judgment, for, should any blunder be made, a breakdown must certainly result.

"To loosen the clamps on the cable, and unlock the pitman from the wrist pin and lower it to the main sill, is but the work of a moment. Dropping the pitman raises the end of the walking beam with the temper screw attached to it, and throws them back from their former perpendicular over the hole, so as to allow the cable and tools to run up freely without interference with them. Steam is now turned on again, and the tools come up.

"When the box of the auger stem emerges from the hole, the engine is stopped. A wrench is slipped on the square shoulder of the bit, and the handle dropped behind a strong pin fixed for that purpose in the floor; another wrench is put on the shoulder of the auger stem; a stout lever is inserted in one of a series of holes bored in the derrick floor in a circle having a radius a little less than the length of the wrench handle, and it is brought up firmly against the upper wrench handle, thus making a compound lever of the wrench and greatly increasing its power. Both men give a hearty pull on the lever, which 'breaks the joint,' or, in other words, loosens the screw joint connecting the bit with the auger stem, so that the bit can be unscrewed and taken off by hand after it has been brought up above the derrick floor. The wrenches are then thrown off, steam is let on again, and the bit rises from the hole. Now the driller throws off the bull rope by operating a lever with one hand, while with the other he catches the bull wheel with the brake, holding the tools suspended a few inches above the floor. At the same instant, the engineer shuts off the steam, or else, suddenly relieved of its heavy work by unshipping the bull rope, the engine would 'run away.' It now remains only to hook the suspended tools over to one side of the derrick, and the hole is free for the sand pump.

"While the driller is sand-pumping, the engineer unscrews the worn bit and replaces it by one newly dressed, so that there may be no delay in running the tools into the well again when sand-pumping is finished.

"The 'line' to which the sand pump is attached, passes over a pulley near the top of the derrick, and thence down to the sand-pump reel, which is operated from the derrick. While sand-pumping, the pitman remains disconnected, the bull rope lies slack on its pulleys, and the band wheel is kept constantly in motion. A slight pressure on the lever brings the friction pulleys in contact with the band wheel, and the pulley immediately revolves, the slack sand-pump line is quickly wound up, and the sand pump, which is usually left standing at one side of the derrick, swings out to the center and commences to ascend. Just now

the lever is thrown back, and the connection between the friction pulley and the band wheel being thus broken, the sand pump commences to descend into the well by its own gravity. If it be likely to attain too great speed in its descent, a movement of the lever, to bring the pulley either forward against the band wheel, or backward against the brake post, will quickly check it, and thus the speed may be regulated at will.

"As soon as the pump strikes bottom, additional steam is given to the engine, and the lever is brought forward and held firmly, while the sand pump rises rapidly from the well. The sand pump is usually run down several times after each removal of the tools, to keep the bottom of the hole free from sediment, so that the bit may have a direct action upon the rock.

"After the hole has been sufficiently cleansed, the sand pump is set to one side, the drilling tools are unhooked and, swinging to their place over the well mouth, are let down a short distance by the brake, the wrenches put on, and the lever is applied to 'set up' the joint connecting the replaced bit to the auger stem. Then removing the wrenches, the tools are allowed to run down to the bottom, under control of the bull-wheel brake. Connections are now made as before, the driller commences his circular march, the engineer examines the steam and water gauges and the fire, and then proceeds to sharpen the tool required for the next 'run,' and thus the work goes on from day to day until the well is completed."

DRILLING METHODS AND APPLIANCES[1]

This section has been prepared for the purpose of imparting a general descriptive knowledge of the different kinds of mechanical devices employed in the production of crude petroleum. The several practices in use at the present time are based upon

[1] The authors are indebted to E. E. Greve, Chief Engineer, Oil Well Supply Company, Pittsburgh, Pa., for much of the information embodied in this section.

The literature relating to petroleum well-boring is, for the most part, of little value, when one examines it critically in the light of present-day practice. However, a select bibliography has been prepared for ones who may find it necessary to study the subject along broad lines; this follows.

On the "History of Drilling and Deep Well Record," see Bowman, *Petrol. Rev.*, **25** (1911), 239, 240, 275, 276; for an account of a recording apparatus in petroleum drilling, see Coppelovici, *Revista Petrolului*, **1** (1908), 78; on the methods of drilling employed in eastern Europe, see Eastlake, *Trans. Fed. Inst. Min. Eng.*, **3** (1892), 693; flush-drilling has been discussed by Fabianski in *Ropa*, **1911**, No. 8; Fauck has described "Boring Machinery in Petroleum Mining" in *First Internat. Petrol. Congr.*, **1900**, 74; hydraulic drilling machinery in *Naphta*, **9** (1901), 291; and other phases of deep boring in *idem*, **9** (1901), 346, 363, 443; **10** (1902), 378; *Petroleum*, **1** (1905), 45;

fundamentals which have been handed down from the first periods of oil development. The mechanical appliances in use vary somewhat in different localities, although the same principle is employed with some modifications; and each of the different systems of operation in practice to-day, has its advantages and disadvantages, according to the geological formation of the territory in which the operations are carried on. The old or obsolete methods of operation merit no consideration and attention will be given only to the methods as they are being practised to-day; these methods[1] are:

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mechanical and hydraulic drilling has been considered at some length by FITZ, *Naphta*, **16** (1908), 186; for considerations of boring systems, see GEBHARDT, *Org. Ver. Bohrtechn.*, **18** (1911), 97, 109, 124, 135, 163; on "Modern Deep Drilling Practice in Europe," see HALDER, *Mining Mag.*, **13** (1906), 33; oil-drilling by electric power has been considered by HEYNEMANN, *Monit. Int. Pétrol. Roum.*, **6** (1905), 396; on the use of explosives, see MEUSCHEN, *Riga. Industr.-Z.*, **35** (1909), 214; *Naphta*, **9** (1901), 343; the articles by PETIT in *Naphta*, **10** (1902), 63, 107 and 169, are of interest; on boring tools and methods for large holes, see ROMANOVSKI, *Gorn. Jurn.*, **2**, 1; on the use of torpedoes, see *Naphta*, **15** (1907), 390; for the application of electricity in boring, consult ST. EMILIAN, *Monit. Int. Pétrol. Roum.*, **7** (1906), 509; on the "Rationell" boring machine, see SCHENK, *Org. Ver. Bohrtechn.*, **17** (1910), 13; on the "Raky" system, see SIUDAK, *Naphta*, **9** (1901), 47; for a system of boring without removal of instruments, see SOKOLOVSKI, *Gorn. Jurn.*, **2** (1879), 189; on various defects in boring, see *Nepht. Dielo*, **1907**, No. 11; SWIERCZEWSKI has discussed flush-drilling in undeveloped fields in *Ropa*, **1911**, No. 8; on the Canadian system, see WALTER, *Oesterr. Z. Berg-Hütt.*, **32** (1884), 512; on extracting oil from boreholes, see TALBOT, *Eng. Min. J.*, **87** (1909), 1001, and **89** (1910), 1270; for an account of an instrument for ascertaining the inclination of boreholes, see BUNNING and GUTHRIE, *Trans. N. Eng. Inst. Eng.*, **29** (1880), 61; and on water in boreholes, see MIRCEA, *Monit. Int. Pétrol. Roum.*, **7** (1906), 121.

For further information on drilling, consult TECKLENBURG'S "Handbuch der Tiefbohrkunde," 6 vols., Leipzig, **1886–1896**; the "Kalender für Tiefbohr-Ingenieure, Techniker Unternehmer und Bohrmeister" of URSINUS, Frankfurt a. M., **1908**; and ISLER'S "Well-Boring for Water, Brine and Oil," 2d. ed., London, **1911.**

On drilling for petroleum, reference should especially be had to *Report* No. **291** (**1**, 146), *Canada Department of Mines, Mines Branch*, **1914**; and to *Bulletin* **69** of the *California State Mining Bureau*, **1914.** Rigs and equipment have been ably discussed by PAINE and STROUD in their "Oil Production Methods," **1913,** 55 *et seq.*

The evolution of drilling rigs has been considered at length by R. B. WOODWORTH in *Bull. Am. Inst. Min. Eng.*, **1915**, No. 107, 2247–2312.

[1] For a full account of the Pacific coast methods of production—some experts state that the California drilling practice embodies the most advanced methods in the industry—see PAINE and STROUD, *op. cit.*

I. Percussion { Cable tool (American system). Pole tool (Canadian system).

II. Hydraulic rotary system.

III. Combination system.

IV. Hydraulic circulating system.

Percussion or Cable-Tool Method

This method of drilling embodies the dropping and raising alternately of a heavy weight (which is the weight of the tools), so that repeated blows will be delivered to the formation through which the well is being drilled. The outfit necessary to carry on this system consists of:

No. 1. Derrick (includes wheels for operating cables, all sills and frame work).
No. 2. Boiler.
No. 3. Engine.
No. 4. Tools and accessories, such as wrenches, bailer, forge, etc.
No. 5. Sand reel.
No. 6. Sand line.
No. 7. Drilling cable.
No. 8. Crown block.

There are three kinds of drilling rigs: the "Standard," which rig is used principally in the east; the "California" rig, used mainly in the middle west and south; and the "California Imperial" rig, which is used principally in California and Canada, and extensively in foreign countries. The important advantage of the "California" and "California Imperial" rigs is that these rigs are so constructed as to facilitate greatly the handling of long and heavy strings of casing.

"Standard" Rig.—The "Standard" rig, as shown in Fig. 59, consists of the following:

A	Nose sill	F	Tail post
$A^{1, 2, 3, 4}$	Mud sills	R^1, R^2	Bull-wheel posts
B	Main sill	R^3	Bull-wheel post brace
C	Subsill	K^1	Sand-reel lever
D	Sand-reel tail sill	K^2	Sand-reel handle
N	Derrick foundation posts	J	Walking beam
O, O^1	Derrick sills	S	Headache post
m–m^1	Engine mud sills	M	Pitman
l^1, l^2	Engine pony sills	X	Crown block
l	Engine block	Y	Sand-sheave pully block
n	Bumper, engine block to mud sill	J^1	Adjuster board

P, P[5]	Derrick floor sills	T	Derrick legs
Q	Derrick floor	U	Derrick girts
I	Samson post	V	Derrick braces
I[1], I[4]	Samson post braces	K[2]	Reach
I[2]	Samson post brace	W	Ladder
I[3]	Samson post brace		
G, H, E	Front and rear jack posts, and knuckle post		
k	Engine		
K	Sand reel		
L	Band wheel		
g	Bull wheel		
f	Bull-wheel brake lever		
q	Sand line		
t	Telegraphy cord		
t′	Throttle wheel		
y	Drilling cable		

The rig shown in Fig. 59 gives an idea of what is required to constitute a "Standard" rig, with the exception that the boiler, forge, tools, bailer, and wrenches are not shown.

To operate this rig, the tools are attached to the drilling cable (r). The cable then passes over the crown pulley on top of the derrick and down and is spooled and fastened on and to the bull wheels (g). The tools are then lowered into the hole, provided drilling has been carried on. This is accomplished by raising the derrick lever (f) and the weight of the tools will cause the drilling cable to be unwound from the bull-wheel shaft. When the tools have reached the proper depth at which drilling is carried on, the lever (f) is forced down and held by means of a chain attached to the floor, thus preventing the unwinding of any more cable from the bull wheels. The pitman (M) is then raised and its lower end is passed over the wrist pin located in the crank on the band-wheel shaft. The temper screw (not shown in figure), which is fastened to the other end of the walking beam, is then attached by means of clamps to the drilling cable. The cable is made either of manila or wire rope as the case may be. Some slack line is finally run off the bull wheels and the driller starts to operate. It is readily seen from the illustration that, by bringing into use the large diameter of the band wheel, great power is obtained, which is necessary in order to swing the tools.

"California Imperial" Rig.[1]—This rig is practically the same

[1] On drilling in California, see JEWELL, *Min. Sci. Press*, **101** (1910), 775; **103** (1911), 44; and HAGER, *Western Eng.*, **2** (1913), 447.

as the "Standard" rig, with the exception that the derrick is usually higher and wider at the base, being 24 ft. square at the base and from 106 to 136 ft. in height. A calf wheel is also used. This wheel effects a great saving of time when much casing is to be handled and is used for operating the casing line, which

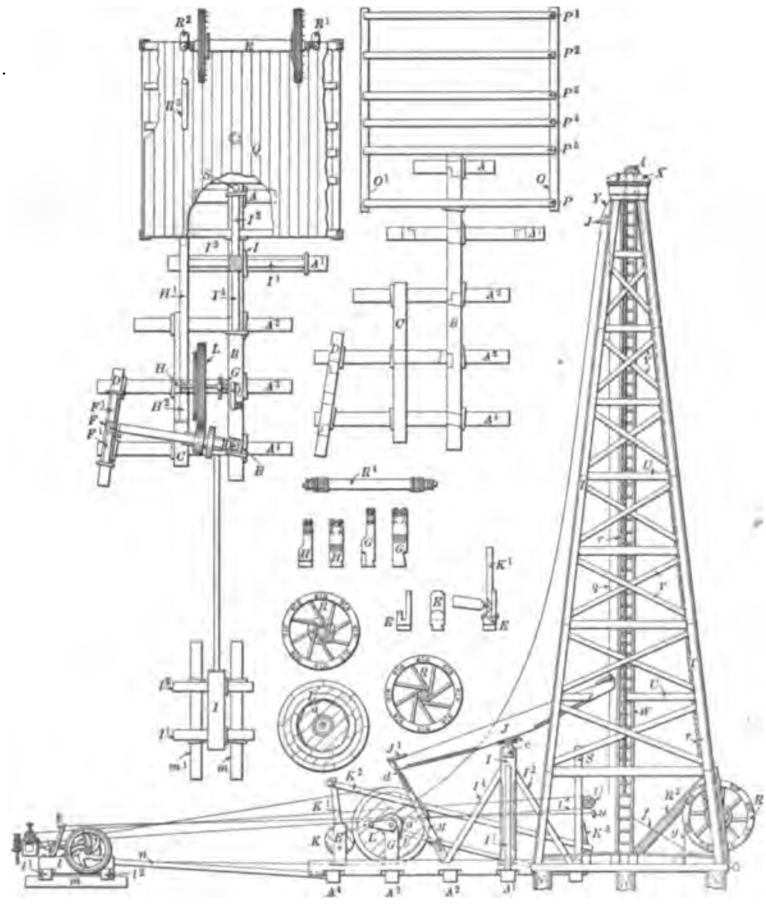


FIG. 59.—Side elevation and ground plan of the "Standard" rig.

line, after being spooled on the shaft of the calf wheel, passes over the pulleys on the crown block and through the sheaves of the casing block. By this means great power can be obtained, due to the fact that there can be as many lines operating between the sheaves on the crown block and the casing block

as there are pulleys. The reason that the calf wheel is not brought into use when operating with the "Standard" rig is that this rig is used principally in localities where casing is only carried down through the surface sand and the hole is then drilled open until completed. In cases where the formation caves, a string of pipe or casing must be carried down with the tools as the depth increases, and invariably it is necessary to work this casing every few hours in order to keep it free. The formation, in caving, comes into contact with the casing and prevents its being moved: it is "frozen." When this occurs, it means that the pipe must be alternately raised and lowered until it becomes free and loose. By having the calf wheel this is readily accomplished, as it simply means the pulling of the tools out of the hole and attaching the elevators, which are suspended from the hook on the casing blocks to the casing. The calf wheel is then operated by throwing in a clutch on the band-wheel shaft.

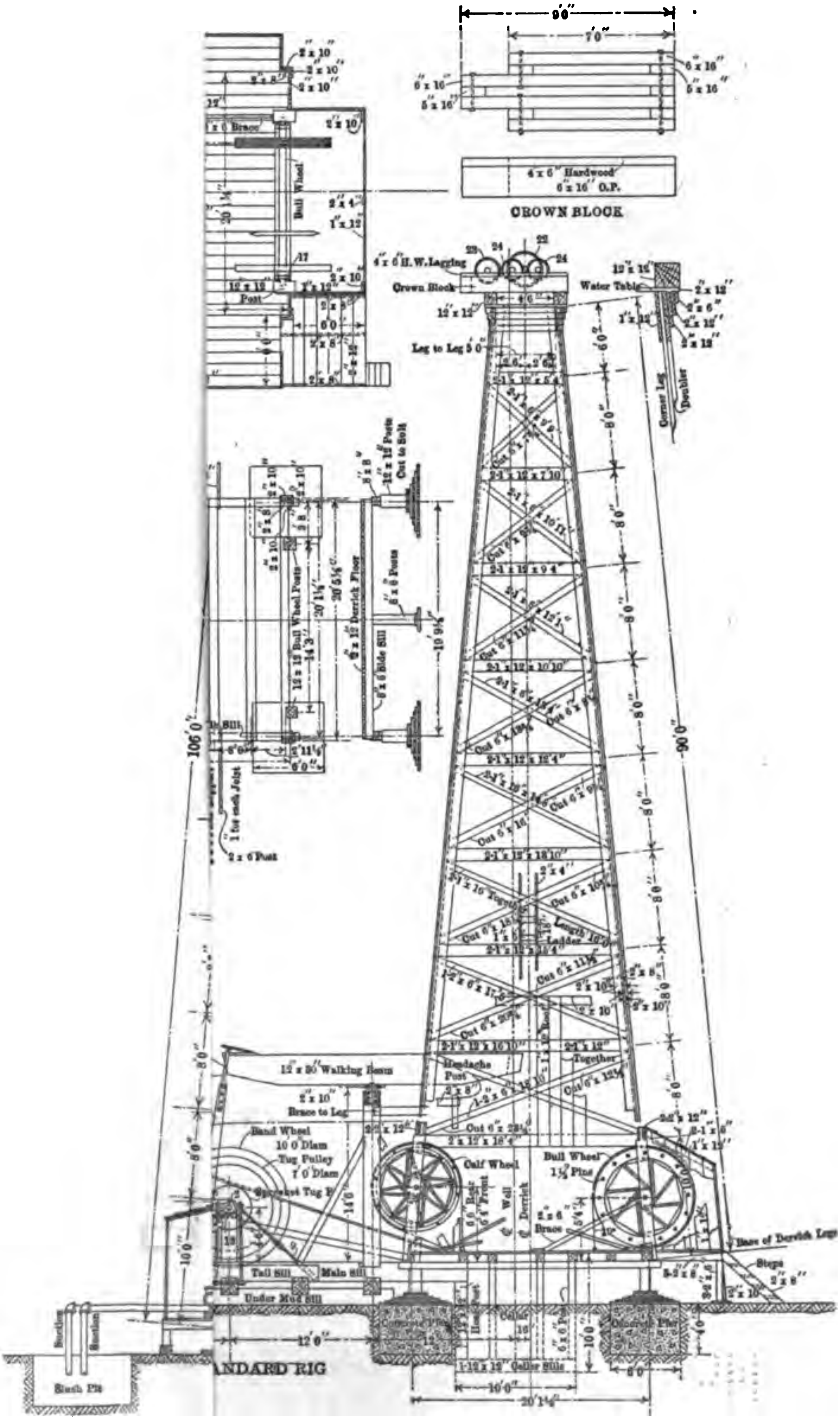
Fig. 61 shows the plan of the "California Imperial" rig.

"California" Rig.—This rig is the same as the "California Imperial" rig, with the exception that it is not nearly as heavy; the derrick is not as high and the calf wheel is not driven by means of a sprocket chain. The sprocket rim on the calf wheel and clutch sprocket on the band-wheel shaft of the "California Imperial" rig are replaced by a rim and tug pulley with which a rope drive is used and the clutch is dispensed with. This method is not nearly as easy to operate as the sprocket drive for the reason that the rope has to be thrown off and on by the driller's assistant or tool dresser and no clutch is used.

Derricks are also built of structural steel and pipe as shown in Figs. 62 and 63. The advantages claimed for these derricks are that there is less resistance to the wind, they are easily erected and dismantled, and the deterioration is not as great as that of the wooden derrick. The steel or pipe derrick can be easily painted and its life of operation may be thus prolonged.[1]

Very often drilling operations are to be carried on in places where it is difficult to move in heavy machinery and the portable machine is then used. These are made in quite a variety of designs, the main object being to have a machine which can be moved from one location to another without incurring a great

[1] On the advantages of steel drilling rigs, see R. B. Woodworth, *Bull. Am. Inst. Min. Eng.*, **1915**, No. **107**, 2247–2312.



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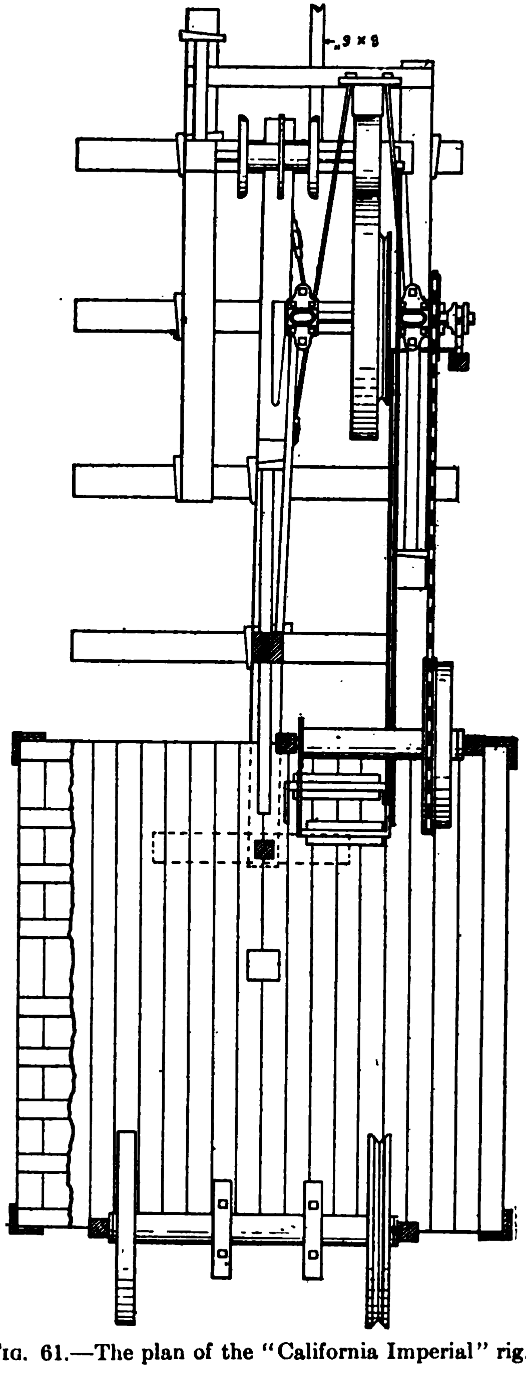

FIG. 61.—The plan of the "California Imperial" rig.

deal of expense. Some of these machines are mounted on wheels and are hauled from place to place, while others are self-propelled.

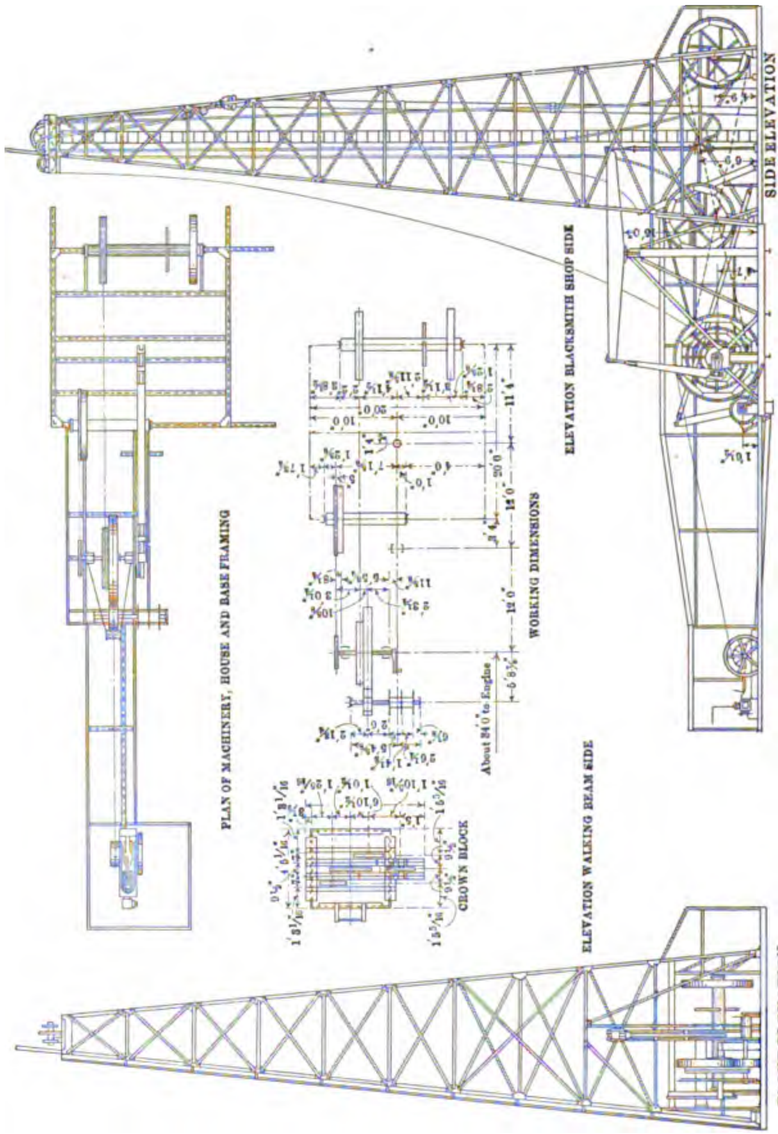

Fig. 62.—Eighty-foot steel drilling rig.

In cases where a rig must be moved in sections, a machine such as shown in Fig. 64 meets with great favor, as it can be taken

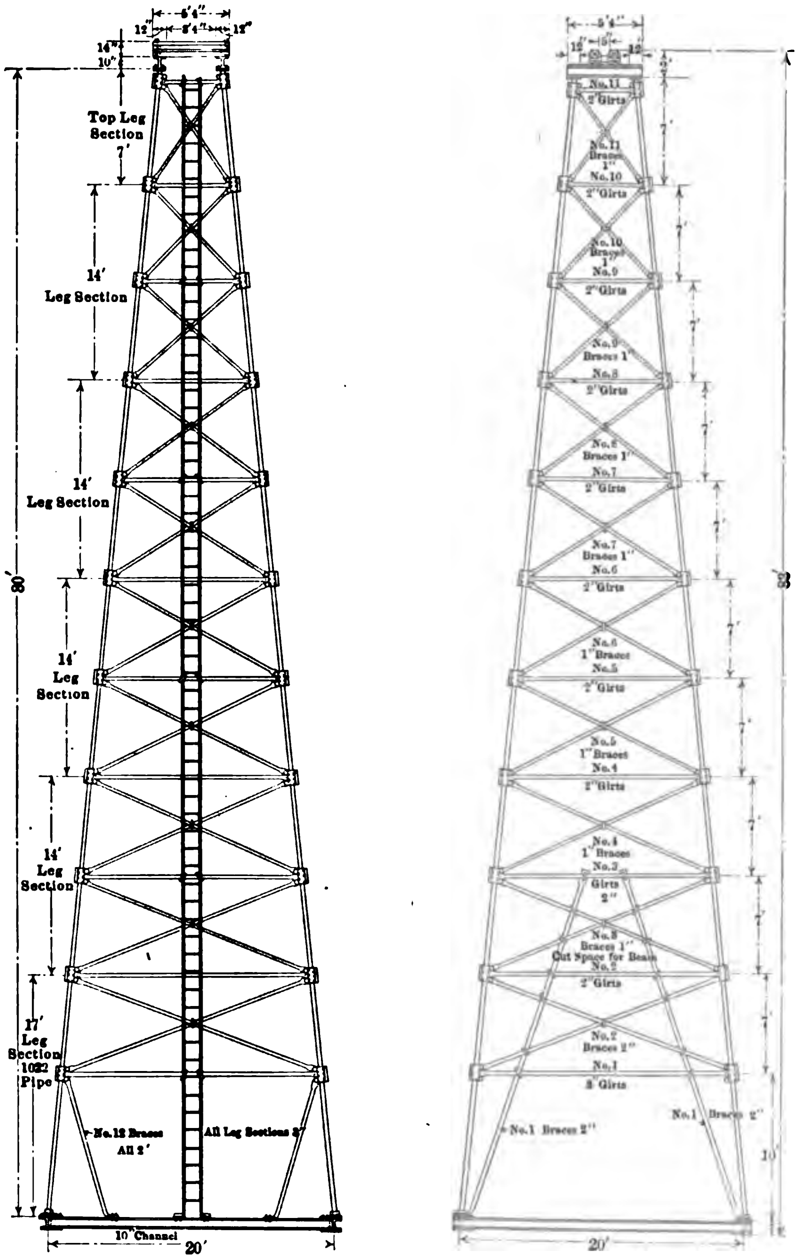

FIG. 63.—The tubular derrick, showing both the ladder side and the walking-beam side.

apart so that no part would be too heavy to transport over rough and difficult ground. These machines are not adapted to drilling to very great depths, but are applicable to holes of average depth.

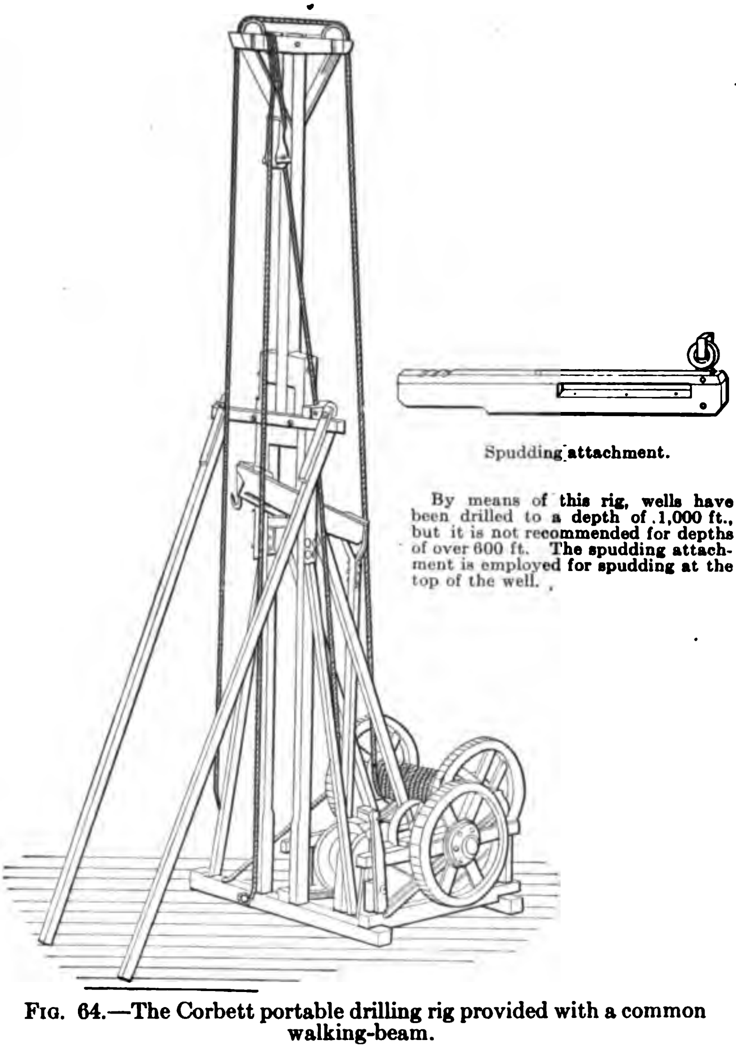

FIG. 64.—The Corbett portable drilling rig provided with a common walking-beam.

Figure 66 shows a traction steam-driven drilling machine, which is made entirely of steel and therefore gives great rigidity; it is especially adapted for drilling where the climate is such that wood would warp, with the result that constant repairs would be

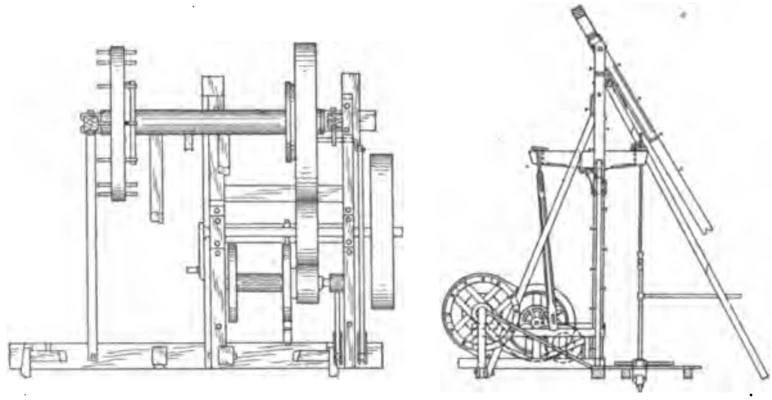

FIG. 65.—The Corbett portable drilling rig.

The figure to the left is the ground plan, showing the arrangement of the timbers, wheels and parts.
In the figure to the right the rig is arranged for pumping.

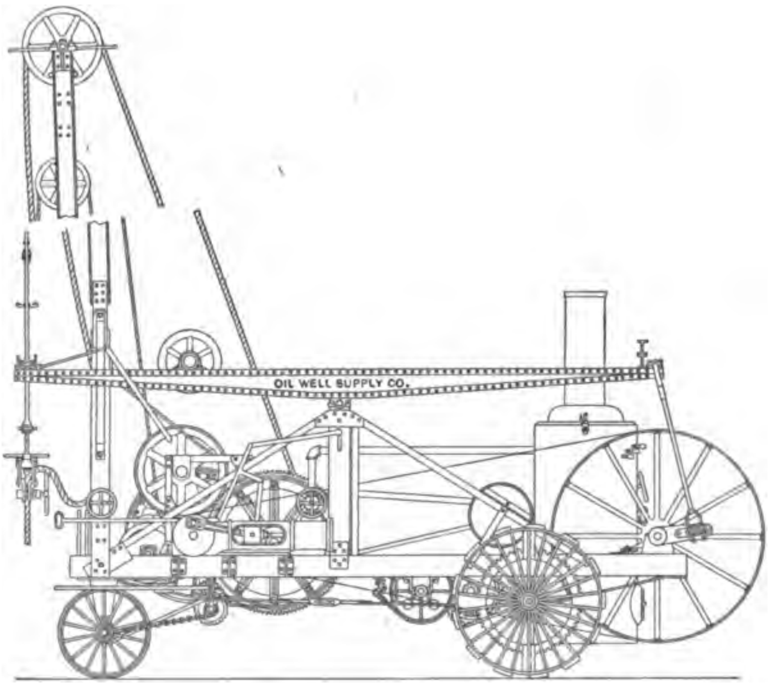

FIG. 66.—The "No. 3 Columbia" driller.

necessary in order to keep the mechanism of the machine in proper alignment. This machine is so constructed that the mast is carried on the machine and can be raised into position and guyed with very little loss of time. The machine is operated by a steam engine through the medium of a belt.

The band-wheel shaft carries the cranks which operate the beam to give the raising and dropping of the tools. Clutches

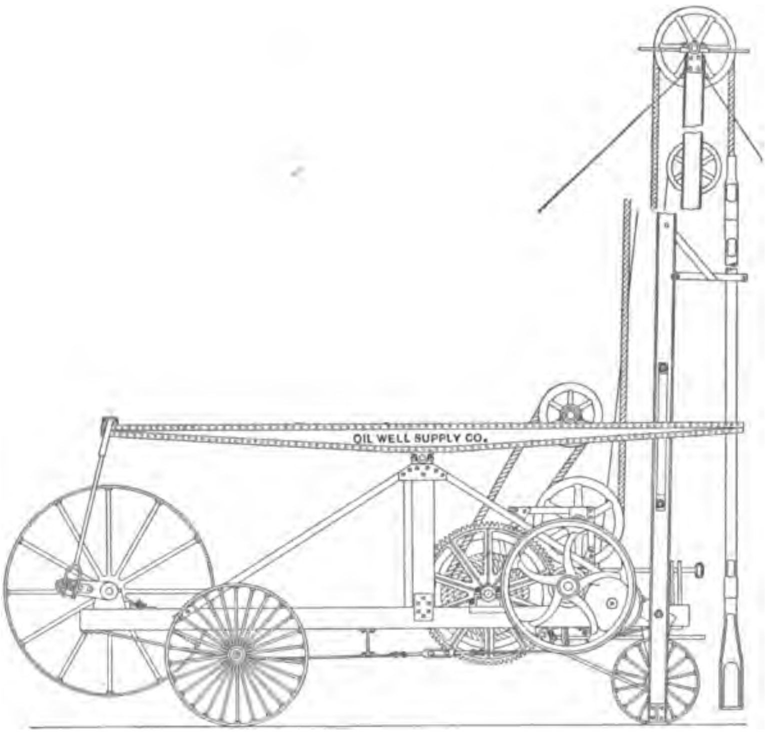

FIG. 67.—The "Columbia" driller.

are used for operating the bull wheel and auxiliary reel, and the sand reel is operated by means of a friction drive.

Figure 67 shows a portable non-traction machine with the cable arranged for spudding. It is easily seen that, when spudding, the raising and dropping of the tools is obtained by the operation of the walking beam. This method gives a very steady and long stroke, which is essential, as it eliminates a great deal of the stress on the machine.

Figure 68 shows a gasoline-driven machine, which is the same as the above mentioned, with the exception that a gasoline engine is used as the source of motive power instead of a steam engine. The gasoline or gas engine has not as yet proved a success in drilling, for the reason that the variation of speed necessary to get the proper operation of the tools is not obtainable. However, this

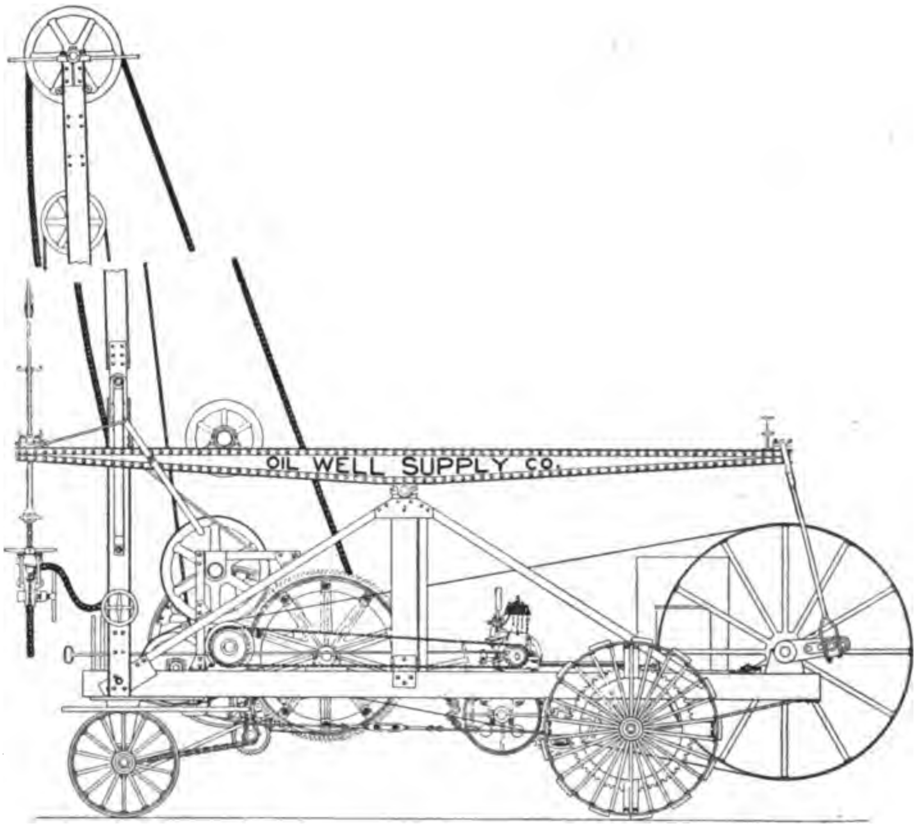

FIG. 68.—Gasoline-driven drilling machine.

source of power is appreciated in cases where water and fuel are scarce.

Boilers.—The boiler used almost exclusively for carrying on well-drilling operations is that known as the horizontal tubular boiler. This boiler is made in two types, known as the "locomotive type," shown in Fig. 69; and the "California type," shown in Fig. 70. The "locomotive type" boiler is one which is

quite extensively mounted on wheels, thereby making it portable and easy to move from one drilling location to another. The "California type" is bricked into position and is not easily moved from place to place.[1]

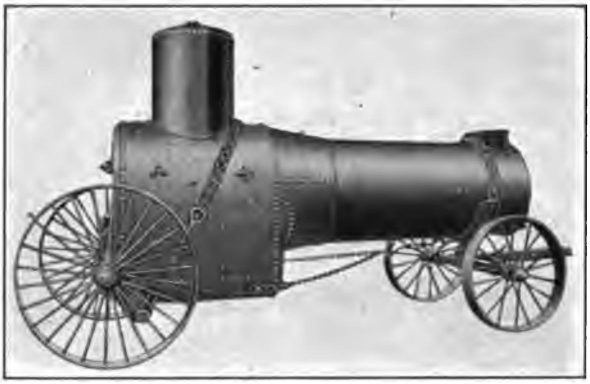

FIG. 69.—Mounted portable boiler of the "locomotive type."

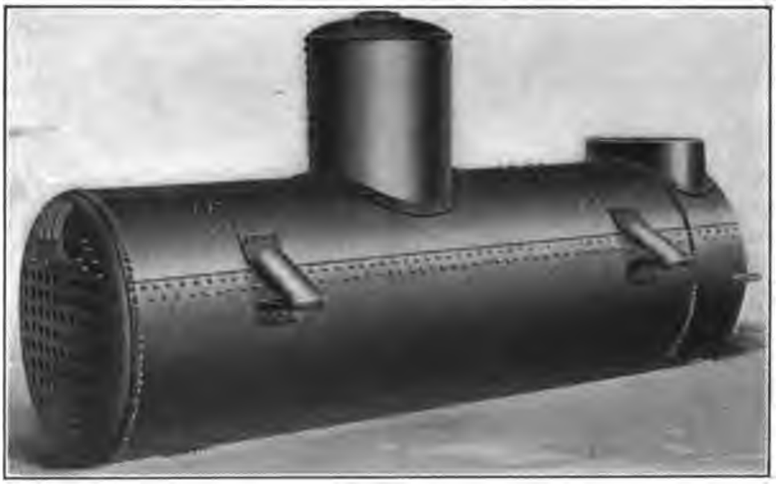

FIG. 70.—Horizontal tubular drilling or pumping boiler of the "California type."

Crown Block.—The term "crown block" refers to those beams which are used on the top of the derrick and which support the pulleys over which the different cables used in drilling operations

[1] See MENZIN, *J. Elec. Power and Gas*, **28** (1912), 51.

are carried. These blocks are now made of steel, as shown in Fig. 71. This block has six pulleys, the four outside pulleys being those used for operating the casing line. The large pulley in the center is known as the crown pulley, and is the pulley over which the drilling cable operates. In line with the crown pulley is a narrow pulley which is known as the sand-line sheave, over which the sand line runs.

Drilling rigs used in the east as a rule employ crown blocks having but two pulleys, the crown pulley and the sand-line sheave. The crown block shown in Fig. 71 is one such as is used in California and foreign countries, as in these localities the geological formation necessitates the use of a crown block which will permit of the use of a casing line which can be operated without inter-

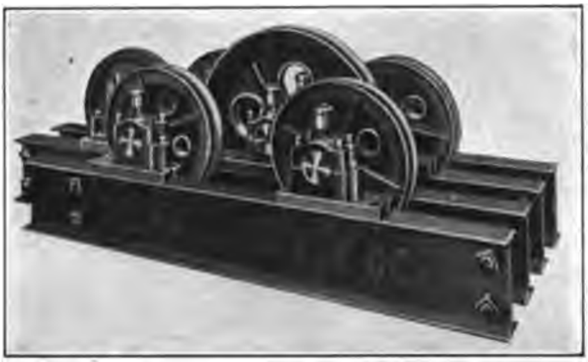

FIG. 71.—Crown block of the type used in California and foreign countries.

fering with the operation of the drilling line or sand line. One corner of the derrick will often settle and will therefore throw the crown block at such an angle that the lines will not hang in the center of the derrick. When this happens, it is customary to jack up the leg of the derrick and level up the crown block. Very often this method is not followed, and, in order to obtain the hanging of the different lines in the center of the derrick, certain sheaves or pulleys are moved. To accomplish this, the bearings carrying the sheaves or pulleys are on a sliding base as shown.

Bailers.—As drilling progresses, the cuttings become mixed with the water in the hole, and, after carrying on operations for a certain length of time, the drillings, together with the water, form a mud which does not permit of the free operation of the

tools. The tools are then withdrawn from the hole, and the bailer attached to the sand line is lowered into the hole and the mud removed. There are a number of bailers, but Figs. 72, 73, and 74 illustrate the general construction. Figure 72 shows a sectional flush joint dart bailer which can be made in any desired length; the object of the flush joint is that this bailer can be used in cases where it is desired to run a bailer of maximum diameter through the casing already in the hole. When this bailer is lowered to the bottom, the dart is raised and the fluid enters in at the bottom. In cases where there is considerable liquid in the hole, it will also enter at the top of the bailer.

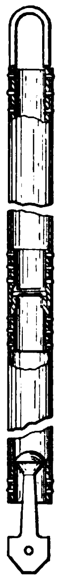

FIG. 72.—Sectional flush joint dart bailer.

Another style of bailer is one which is not a flush joint bailer. Figure 73 shows the top of the bailer and Fig. 74 the bottom. By using the top and bottom, any length of pipe desired can be used, thereby giving a length of bailer which would only be limited by the height of the derrick in which it is to be operated.

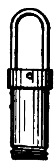

FIG. 73.—Top of a casing bailer.

Sand Pumps.—Where a great deal of sand is encountered, a special pump is used for removing it from the well. Such a sand pump is shown in Figs. 75 and 76. The sand pump is a bailer with a plunger and the valve and seat in the bottom of the pump so constructed that they can be swung downwardly, thereby permitting of the unobstructed dumping or emptying of the pump at the surface. In Fig. 76 the bottom of the sand pump is shown in a closed position, and in Fig. 75 it is shown open and ready for dumping the sand. To open this valve when the pump is loaded, it is merely necessary to allow the weight of the pump to rest on the small pin shown on the inside of the beveled edges of the bailer bottom. This pin is then raised and the string is forced outwardly, thereby releasing the seat and the valve, and the contents of the pump drop out.

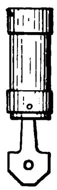

FIG. 74.—Bottom of a casing bailer.

Tools.—The string of tools consists of a socket, drilling jars,

drill stem, and bit. These different tools are joined together by means of box and pin connections, the boxes and pins having a certain definite taper. The construction of one of these joints is shown in Fig. 77; they are made up or screwed together as shown in Fig. 78. This figure shows a rack which is the arc of a circle, two wrenches, a jack and a lever for operating the jack. In order to make up a string of tools, a swivel wrench such as is shown in Fig. 79 is employed in connection with the derrick crane, as shown in Fig. 80.

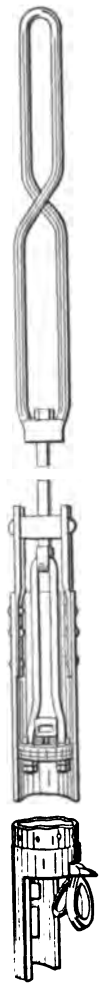

FIG. 75.—"Model" sand pump.

FIG. 76.—"Oilwell" sand pump.

For instance, we will say that we intend to screw the bit into the drill stem. The drill stem together with the socket and jars will be suspended in the derrick from the drilling cable. The swivel wrench will be suspended by a differential block from the derrick crane and the square under the pin of the bit will be placed inside the recess of the swivel wrench. By means of the differential block, the wrench and bit will be raised until the pin of the bit enters the box of the stem. Then, by means of the two projecting handles on the wrench, the bit is screwed into place. The wrench is then removed from the bit, and the bit and rest of the tools are moved over and lowered into the hole until the square of the bit comes approximately a little above the casing or the floor of the derrick. The wrench, Fig. 79, is then passed around the square of the bit and the end of the wrench placed against the wrench post. Insofar as the thread on these joints is right-hand, the other wrench is then placed on the square above the box of the stem. The end of this second wrench rests against the jack. By operating this jack the joint is screwed up until sufficiently tight to permit of the operations being carried on

without the possibility of the joint coming loose. Great care is exercised in making up these joints, as it is very easy to exert too much pressure on the jack and jump the pin, or, in other words, break the pin off. If the joint is not made up sufficiently tight, there is a strong probability of it becoming loose and some of the tools being lost in the hole.

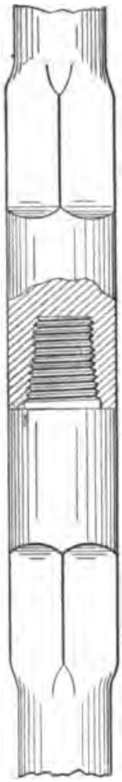

FIG. 77.—The taper joint which is now in general use. This joint has been found to be superior to the old style straight joint.

Rope Socket (*Manila Rope*).—The top of the string of tools, or that part which connects the rest of the string with the drilling line, is known as the rope socket, and such a socket is shown in Fig. 81. To attach this socket to the rope, the following practice is observed: The end of the rope is passed down through the neck of the socket and out through the elliptical hole shown on the side of the socket. Enough rope is passed through so that approximately 10 in. or 12 in. of rope can be unraveled and then small pieces of soft rope, approximately 10 in. long, are laid in between the strands of unraveled rope and at right angles to the lay of rope. The strands of rope are then put back into their original position and the end of the rope is wound with string so as to prevent its unraveling. This will give an enlarged portion of rope near its end, and, due to the weight of the tools, this portion is pulled into the recess in the side of the socket, it being too large to pass through the neck of the socket. When first operating this socket, the rope will project beyond the socket proper, but, due to the friction against the casing when the tools are lowered and raised in the hole, the rope will be worn off smooth. The bottom of the socket has a female thread which is known as the box.

Rope Socket (*Wire Rope*).—Figure 82 shows a rope socket such as is used for connecting wire rope to the tools. This socket shows a rope passing through the sleeve and attached to plug slips at the bottom. This is known as a swivel rope socket, as it permits the tools to rotate in one direction. For instance, when the tools are being lifted, the weight causes the lay of the line to have a tendency to unravel, and, as the tools descend, the line

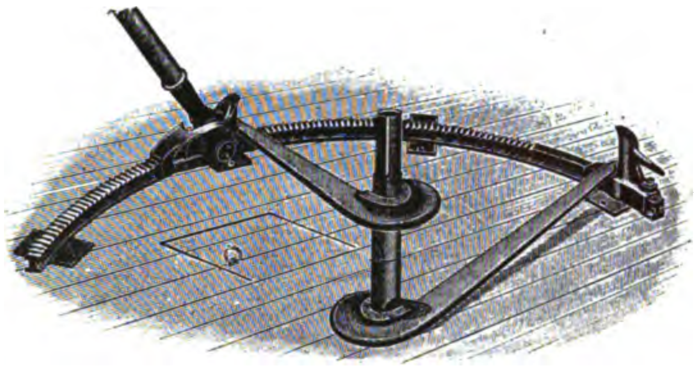

FIG. 78.—The Barrett oil well jack.

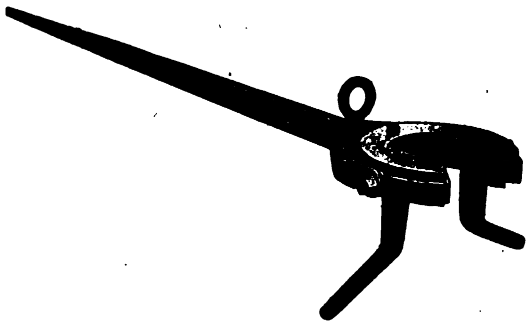

FIG. 79.—The Barrett improved swivel wrench.

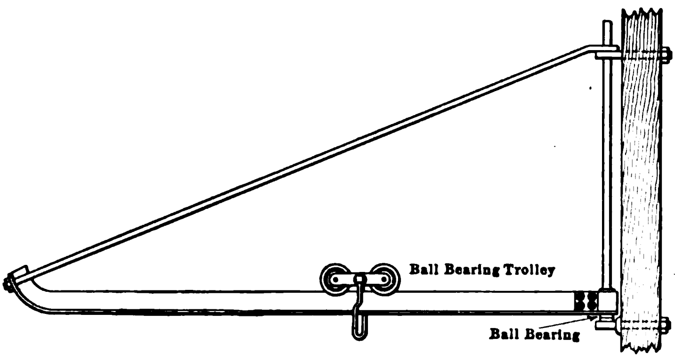

FIG. 80.—Tee-beam ball-bearing derrick crane.

tends to go back into its original shape and, in doing so, causes the tools to rotate, this rotation being facilitated by means of a swivel in the socket. It is readily seen that with this kind of swivel the tools will rotate in one direction, which is a much desired effect.

FIG. 81. —"New Era" rope socket.

FIG. 82. —Rotary rope socket for wire line, Prosser patent.

Jars.—Attached to the socket are jars such as shown in Fig. 83. In some localities jars are not used, but, as they are used in most drilling, they are here included in the string of tools. These jars have a pin on one end and box on the other, and are connected together by means of interlocking links, or reins, as they are properly termed. The jars are principally used in cases where the tools have become stuck in the hole and it is necessary to jar them loose. It is the practice to place the jars between the socket and stem when drilling. In fishing it is very often customary to place the jars below the stem, so that the weight of the stem may be brought into play to give a heavy blow.

This appliance was introduced in 1831 by William Morris; it was at first known as the "slips" and was employed in brine-well drilling.

Stem (Auger).—A stem such as shown in Fig. 84 is the next tool below the jars used in the string. These stems are solid and are of such length and diameter as are required by the hole in which operations are being carried on.

Sinker Bar.—Figure 85 shows a sinker bar, which is of the same construction as the stem, but is approximately one-third as long. The sinker bar is not very often used, but, when used, is placed between the jars and the socket. The function of this bar is to give more weight to the blow on the jars when drilling in clay or sticky formation, for in this case a bit has a tendency to stick. The blow mentioned is that required to release the bit should it become stuck.

Bit.—Figure 86 shows a drilling bit, which is attached to the lower end of the stem. This bit is dressed in different ways, according to the ideas of the driller and the nature of the formation.

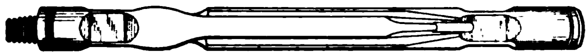

FIG. 83.—Drilling jar.

FIG. 84.—Auger stem.

FIG. 85.—Sinker bar.

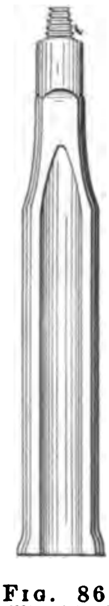

FIG. 86.—Drilling bit, California pattern.

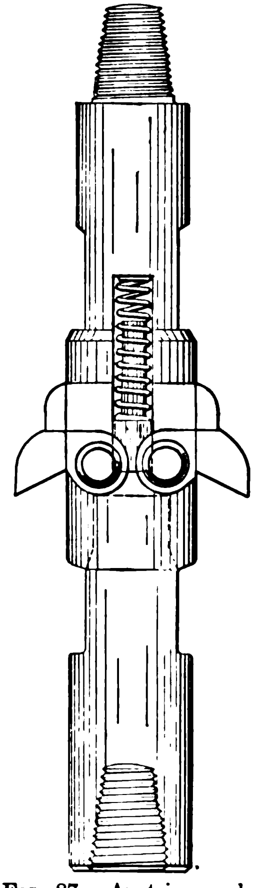

FIG. 87.—Austrian underreamer for reaming out drilled holes.

In some cases the bottom edge is beveled and in other cases it is dressed concave. In drilling it is necessary to keep this bit up to gauge, so that the hole will be kept true and will not have to be

reamed out in order to permit of the placing of casing in the hole. Also, if the bit gets too much out of gauge, the hole will become conical; and should a new bit dressed out to gauge be then run into the hole, it will stick and cause considerable trouble in getting it loose.[1]

Underreamer.—An underreamer is shown in Fig. 87. The purpose of the underreamer is to ream out a hole after it has been

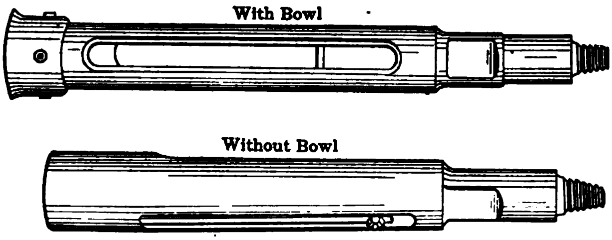

FIG. 88.—Slip sockets.

drilled, so that casing can be readily inserted. In the figure the cutting knives are shown in operative position; that is, the knives assume this position as soon as the underreamer has passed through the bottom joint of the casing and into the open hole. The underreamer, in passing through the casing, has these knives closed inside of its body, and, as soon as they are free from the casing, they are forced out into operative position by means of a spring.

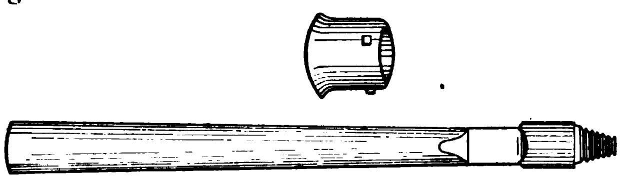

FIG. 89.—Horn socket and bowl.

Fishing Tools.—To carry on drilling operations successfully, it is essential that fishing tools should be readily obtainable. There are a great many conditions which can take place, such as the losing of tools in the hole, due to breakage of some part in the string, parting of the line, caving, or, in fact, mishaps too num-

[1] As the hole is never drilled quite true, and an allowance has also to be made for the larger diameter of the sockets connecting the lengths of the casing, a 13-in. bit is used for drilling a hole which is to receive 10-in. casing, a 10-in. bit for $7\frac{5}{8}$-in. casing, and a $7\frac{1}{2}$-in. bit for $5\frac{5}{8}$-in. casing.

erous to mention. New tools for different fishing purposes are being constantly placed before the public and two of these are shown in Fig. 88, a slip socket with and without a bowl. The slip socket is, as the term implies, a socket in which operates a slip. This socket can be run into the hole and, passing over the lost tools, is then raised, at which time the slips take hold and the lost article is removed from the well.

Horn Socket.—This socket has the same function as the slip socket, with the exception that no slips are used and, by jarring down on the socket, a friction hold is taken on the lost tool. If the hole is of such diameter that the lost article rests against the wall or side of the hole, a bowl such as shown in Fig. 89 is attached to the bottom of the socket. The function of this bowl is to guide the lost article into the socket itself.

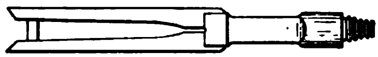

FIG. 90.—Boot jack, which is used as a bailer grab and also to take hold of broken jars.

Boot Jack.—This jack has a plate pivoted to one of the jaws. In lowering the jack down into the hole, this latch is raised when it comes in contact with the article to be removed, and the bail of the bailer, or any such article, passes up in between the jaws of the jack. As the tools are now raised, the latch seats itself, and the bail or article is retained in the jack and removed from the well.

Jar Knocker or Bumper.—Very often in pulling tools out of a well they become caught under the drive shoe or lower joint of

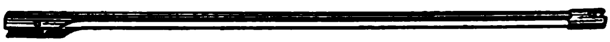

FIG. 91.—Jar knocker or bumper.

casing and must be jarred loose. When this happens, such a tool as shown in Fig. 91 is attached at its upper end to the sand line. The lower end passes around the drilling line. It is then lowered into the hole and bumped on top of the socket until the tools have become loosened.

Rope Knife.—Where the tools have become stuck and cannot be removed, due to the fact that no action can be obtained by bringing into play another string of tools, it is the practice to cut off the rope or drilling line close to the socket. This is accomplished by passing the drilling line through a rope knife and lowering this knife down on the line until it gets into such a posi-

tion as to enable the rope to be cut. Then, by jarring down on the mandrel, the knife is extended and the rope cut. The rope and knife are then withdrawn and a string of tools lowered into the hole. On the bottom of the fishing string a slip socket is used, which socket passes over the rope socket of the lost string. By jarring up on the second string of tools, the first string will become loosened.

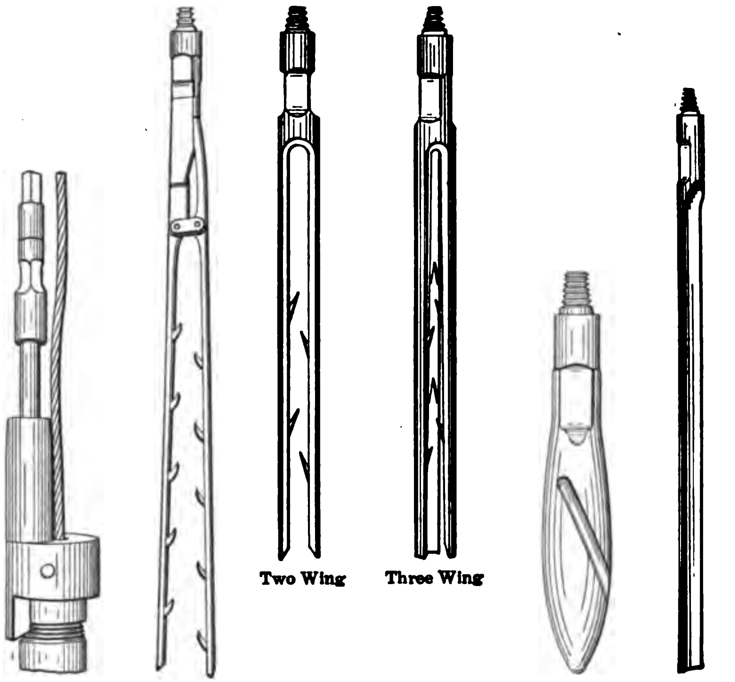

FIG. 92. Hall Patent FIG. 93. FIG. 94. FIG. 95.

FIG. 92.—Mapes patent knife for cutting wire rope.
FIG. 93.—Rope grabs.
FIG. 94.—Fluted swedge, for opening a clear passage through collapsed pipe or casing.
FIG. 95.—Spud, a tool for spudding around and loosening a bit or reamer when fast in the well, if disconnected from the rest of the tool. The usual length of the blade is 8 ft.

Rope Grabs.—Figure 93 shows different tools for fishing out lost cable in the hole. The tools are operated by lowering them into the hole and the prongs pass down through the coils of rope therein. When pulling up, the rope becomes caught on the inwardly upward projecting prongs, and is thereby removed from the well.

Swedge.—Should casing collapse, it is customary to run a swedge, so that the pipe can be forced out to its original diameter. It is also a practice to run a swedge through new strings of casing which have been placed in the hole, in order to insure the proper inside diameter of the pipe necessary to enable the bit to pass through.

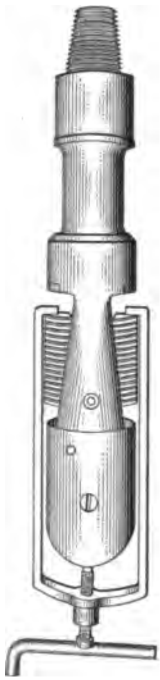

FIG. 96.—The Henderson trip casing spear, showing the method of setting slips.

Spud.—In cases where a bit or reamer has become stuck in the hole and disconnected from the rest of the string of tools, a spud is lowered into the hole and, by means of raising and lowering, the accumulation of the material holding the lost tool is pushed out of the way, thereby freeing the tools so that they can be withdrawn from the well by means of one of the well-known fishing tools.

FIG. 97.—The Henderson trip casing spear, showing the slips released from the casing hold and locked to insure free passage from the well.

Spears.—Figure 96 shows a spear being set, and Fig. 97 shows the slips released from the casing and locked to insure free passage from the well. The slips have an inclined tapered face which fits the inclined face in the body of the spear. These two slips are carried on a crossarm which operates against a spring. Before the spear is lowered into the hole, the slips are drawn down to the lower end of their travel by means of the setting tool, as shown in Fig. 96. When the slips have been drawn down the required distance, they are held in place by means of a latch and the setting tool or yoke is removed. There is some play in the crosshead which enables the slips to have some loose motion, so that, when the spear is lowered into the hole, the slips, due to their contact with the casing, will ride freely on the tapered body of the spear and against the casing. The serrations on the slips extend upwardly, so that the slips will pass in the hole when descending

and will not allow the spear to be withdrawn from the hole without being set, as shown in Fig. 97. To operate this spear, it is attached to the bottom of the string of tools, or, in other words, it replaces the bit on the string of tools. It is then lowered into the hole until it is at the desired position. By pulling up on the drilling line, the slips are forced against the casing and, by jarring upward with the tools, the casing is supposed to become free. Very often it is not possible to free the casing, and, when such is the case, it is necessary to withdraw the tools and try some other method, such as jacks. In order to withdraw the spear, the tools are allowed to jar downwardly. By this means, the slips are released from the casing and the action of the spring against the crosshead forces them up against the shoulder of the body of the spear, as shown in Fig. 97. The spear is then entirely free and can be readily withdrawn from the hole.

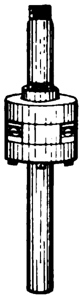

FIG. 98.—Casing cutter.

Casing Cutter.—When it is necessary to cut off the casing in a well, a casing cutter, such as is shown in Fig. 98, is brought into play. This cutter is lowered on a string of tubing down inside of the casing, until the point at which the casing is to be cut is reached. The tubing is then held by elevators which rest on a rotating plate. A string of rods with a mandrel, with the wedge and jar as shown in Fig. 99, is then lowered into the tubing and enters the casing cutter body. Due to the weight of the rods above the wedge or to the action of the jars, the wedge forces the cutting knives or cutting wheels out against the casing. By rotating the tubing, the blocks carrying the cutting knives are also rotated, and, due to the expansion of the cutters by means of the wedge, the casing is cut.

FIG. 99.—Wedge and jar for casing cutter.

Casing Perforator.—It is sometimes desired to use a casing perforator for the following reasons: First, to split the casing in when it has become frozen and the intention is to release it by allowing the material on the outside of the pipe to pass in through the pipe. Second, it is used in cases where strainer pipe is not used and after a well has been completed, when the casing is to be perforated in order to allow the fluid or gas to enter the well. The casing perforator shown in

Fig. 100 works in the following manner: There is a block carrying the knives which operates on an inclined face inside of the body of the perforator. Suspended from the bottom of the body, this block has a rod, at the bottom of which is a spring latch. Around this rod is a spring. Fig. 100 shows this perforator in position to be lowered into the well. In being lowered, the spring on the rod beneath the body will be in contact with the casing. When the point at which perforation is to be carried on is reached, the body of the perforator is raised and, due to the friction of the spring against the casing, the spring remains stationary and the latch on the bottom of the rod is pulled through the bottom of the spring. As the body is again lowered, the latch seats itself on the inside of the spring, thereby causing the rod to project up into the body of the perforator and forcing the inclined cutter blocks into a position whereby they will be in contact with the casing. As the weight is applied above the body of the perforator, the blocks carrying the cutters will slide on the upwardly outward tapered faces and puncture the casing. By continuously raising and lowering the perforator, the pipe can be punctured in a number of places, and it can, at any time, be withdrawn from the well.

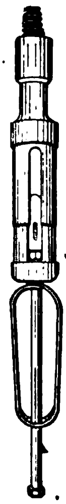

FIG. 100.—Casing perforator, showing position of perforators when the tool is being lowered into the casing.

Production.—After a well has been completed, it becomes necessary, providing the well does not flow, due to insufficient pressure, to use means for elevating the oil to the surface.[1] This is accomplished by inserting in the well a string of tubing which is usually 2 in. or 3 in. in

[1] The amount of power required in the various operations of pumping wells is indicated by the following tests, with a steam engine, on wells producing oil of about 15°Bé.

Depth of well	Pumping depth	Revolutions per minute	Indicated horsepower
1,065	860	96.4	6.1
1,075	920	71.6	4.7
1,056	840	55.0	2.8
929	840	84.8	2.6
1,023	960	56.3	3.0
1,050	980	10.3	4.4

diameter. At the lower end of this tubing a pump barrel is attached. Such a pump is shown in Figs. 101 and 102. In the bottom of this barrel is placed a standing valve, and a plunger is operated by means of rods which pass up through the tubing and are attached to some actuating means at the surface. The difference between the pumps shown in these two figures is that in Fig. 101 a plunger is used which is made of an upper valve and a set of leather cups below this valve. In case it is necessary to withdraw the working valve of this pump, it only necessitates the pulling out of the rods; but if the standing valve

---

Average indicated horsepower	3.91
Average pumping depth (feet)	932.9
Average pumping speed (revolutions per minute)	78.6
PULLING RODS—LENGTH, 940 FT.; SIZE OF ENGINE, 9 IN. × 12 IN.	
Average revolutions per minute	212.8
Total time (minutes)	25.0
Average indicated horsepower	14.08

Another series of careful tests on five wells showed an average consumption of 6.98 hp. per well in pumping. The engine and band wheel absorbed 22 per cent. of that power.

PULLING TUBING

Average revolutions per minute	219.9
Number stands	18.0
Total time (hours)	1.0
Size (inches)	3.0
Length (feet)	940.0
Average indicated horsepower	14.85

LIFTING SAND PUMP

Number of lifts	3.0
Size of pump	6″ × 16′
Lift feet	1040.0
Size cable (inches)	⅞
Average revolutions per minute	182.46
Average time per lift (minutes)	6⅓
Average indicated horsepower	25.4

On oil well pumping methods, see COX, *Western Eng.*, **1** (1912), 93; and HUTCHINSON, *ibid.*, 349. On pumping by compressed air, see ABRAMS, *ibid.*, 234; and IVENS, *ibid.*, 466. Pumping by electricity is accomplished by individual motors and a central transformer plant. On pumping oil wells by electricity, see TAYLOR, *Gen. Elec. Rev.*, **17** (1914), 622; GASSAWAY, *Western Eng.*, **3** (1913), 273; and VAN NORDEN, *J. Elec. Power and Gas*, **28** (1912), 423. For a comparison of electricity with steam power, see *Bull.* **69** of the *California State Mining Bureau*, **1914**, 160 *et seq.* On pumping California crude oil, see BOWIE, *Eng. News*, Dec. 2, **1915**.

is to be removed, a socket or other means is run in through the tubing after the rods have been withdrawn and the standing valve extracted. Fig. 102 is a pump known as the "plunger pump." In this pump the cups are replaced by means of a tight-fitting plunger, which operates over a rod having a head at one end and attached to the standing valve on the other. It is readily seen that by this means the standing valve is withdrawn at the same time as the rods.

Fig. 101.—Brass working barrel or deep well pump, with ball valves.

Fig. 102. The "Imperial" plunger pump.

The methods of actuating these pumps differ. In one the rods are actuated by fastening them to the end of the walking beam. Another means, the method employed where the derrick, beam, etc., have been removed, is shown in Fig. 103. This mechanism is known as a pumping jack, and, by attaching pull ropes or pull rods to the lower strap, the pump is operated. These jacks are operated in the following manner: A pumping power, illustrated in Figs. 104 and 105, is installed and operated by means of a belt drive from an engine. Fig. 105 shows a structural steel power having two eccentrics; by means of a belt drive, power is transmitted from the pinion to the master gear and the eccentric hubs rotate inside the eccentric straps, thereby giving a back-and-forth movement to the pull ropes or pull rods, which are attached to the eccentric straps and to the pumping jack. In cases where heavy duty is to be performed and it is essential to have the pull rods close to the ground, a power such as shown in Fig. 104 is installed. In making this installation, the large wheel of this power acts as a pulley and is operated by a belt drive from an engine. An idler is installed between the engine pulley and the band wheel, which gives the proper turn of the belt, enabling it to ride freely on the face of the band wheel. The main feature of a power of this design is that the pull rods operate

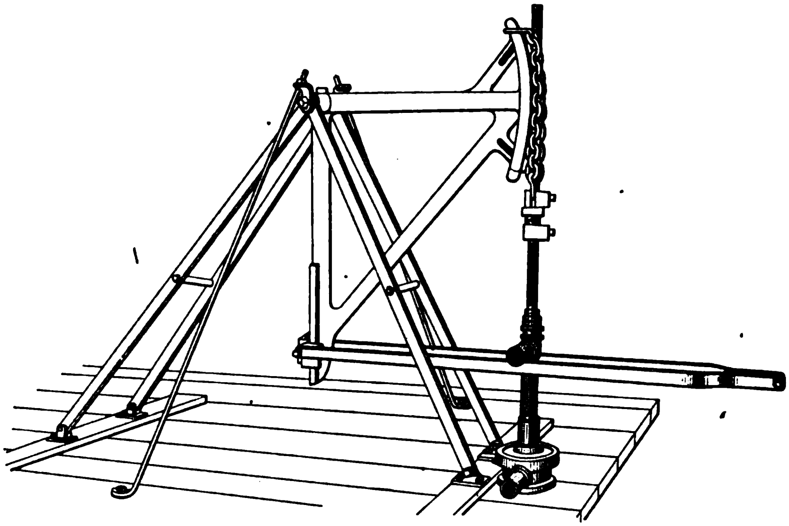

FIG. 103.—The "Simplex" pumping jack.

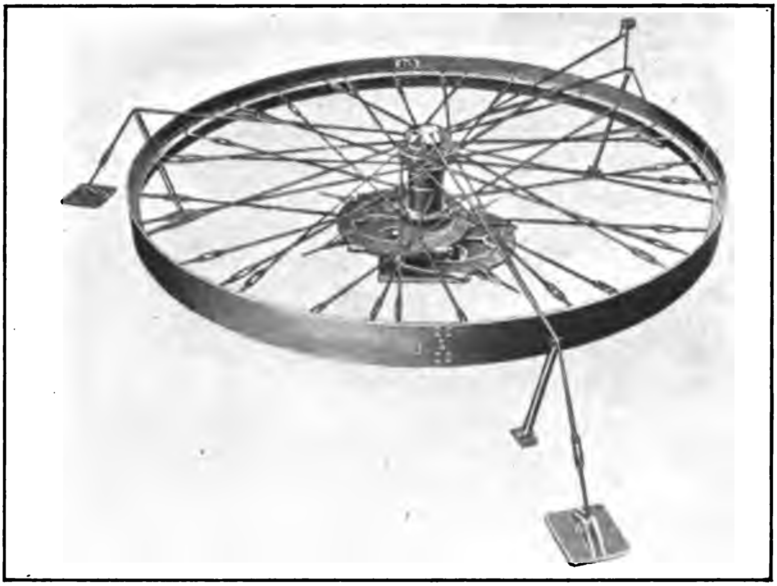

FIG. 104.—Steel band wheel pumping power.

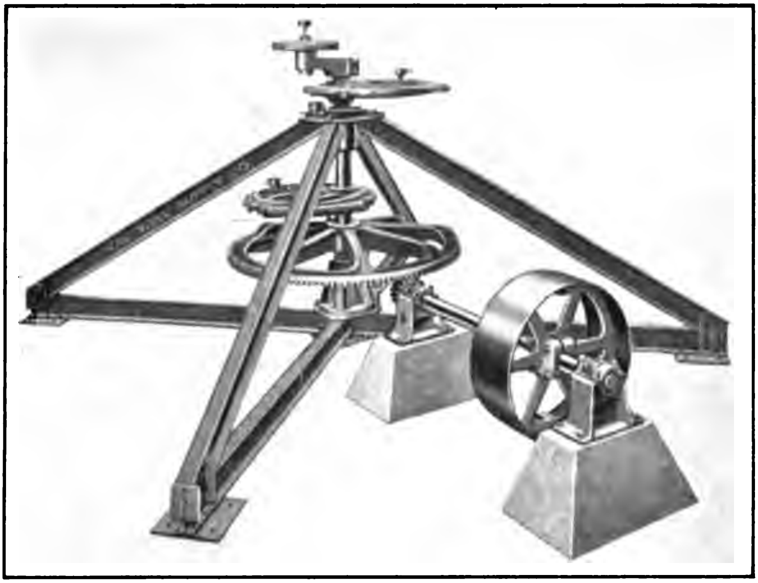

FIG. 105.—California structural steel pumping power.

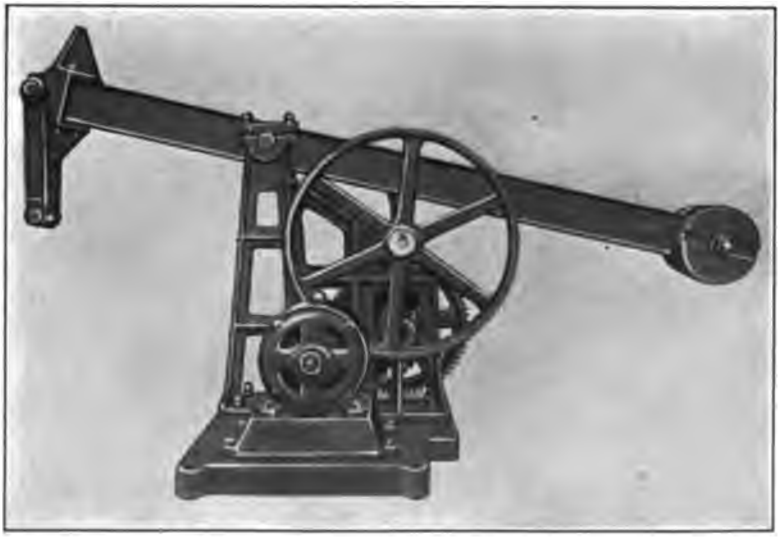

FIG. 106.—Unit pumping power with electric motor.

close to the ground, all bearings will operate in an oil bath, and there is no possible chance of the power getting out of alignment and thereby causing undue stress on the working parts.

FIG. 107.—Wooden sucker or pump rod.

There are cases where it is not desirable to install a pumping power and jacks, for the following reasons: (1) the wells are too few in number; (2) the distance between the wells is too great; and (3) the property is too valuable to have a net work of rods playing over the surface, thereby preventing the working of the land. A power, as that shown in Fig. 106 and known as the unit pumping power, is then installed. The figures hows the power operated by means of a motor, although an engine is very frequently used. Weights are placed on the end of the beam, the intention being to balance up the beam, so that a minimum amount of power is required to carry on operations. The action of this power is as follows: A gear pinion on the motor or engine shaft drives the large gear wheel. On the opposite side of the power and on the same shaft is another pinion which meshes into the second large gear wheel. To this second gear wheel is attached a crank pin and to this crank pin the pitman from the beam is attached. It is apparent that, in operation, power transmitted by the motor operates the beam through the action of the intermediate gearing to the pitman.

Sucker Rods.—Sucker rods are made of iron, steel, or wood. Fig. 107 shows a wooden sucker or pump rod having metal wings attached, these wings embodying a box and pin, which are necessary in order to connect up these rods so that they can be used for actuating the pump in the well.

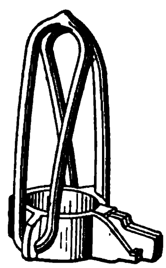

FIG. 108.—Fair's patent elevator, regular pattern of malleable iron.

Elevators.—The casing, each string of which extends from the mouth of the well, is generally made up in lengths of 17½ to 20 ft., screwed together, and is raised and lowered by means of a casing elevator, such as is shown in Fig. 108. This elevator has two links and is hinged at the back. There is a latch which locks the two halves of the elevator together when it has been attached to the pipe, and the links or bails are the means of connecting the elevator to the casing block hook. This

elevator is attached to the pipe below the collar, against which it bears.

Sometimes it is desirable to use an elevator having but one bail, and, when this is the case, an elevator like that shown in Fig. 109 is used. This elevator is made with a body having trunnions attached thereto and has two doors hinged on this body which open and close to admit the entrance of pipe; these doors are locked together by means of vertically actuating bolts and such a design of elevator is the strongest that has ever been placed on the market.

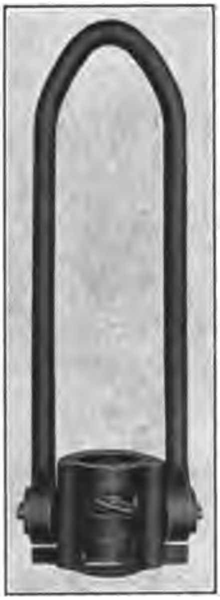

Fig. 109.—Elevator.

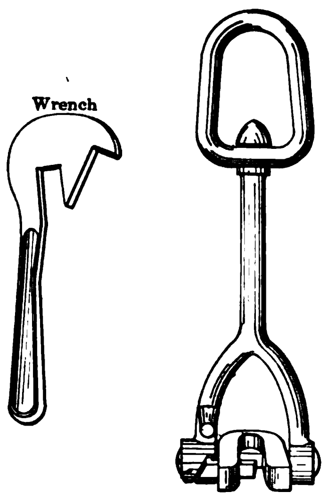

Fig. 110.—Windsor sucker rod elevator.

For the handling of sucker rods, an elevator of different design is used (see that shown in Fig. 110). This elevator is attached to the square of the sucker rod located below the joint and is locked automatically by means of a latch which is actuated in accordance with the motion of the bail of the elevator.

Casing Swivel and Ring.—When inserted- or flush-joint casing is used, a casing swivel, constructed of a short nipple of the particular sized pipe being handled, is employed. For holding the casing suspended in the well, or for gripping it when being "jacked," a casing ring or "spider," having hardened slips or wedges of different sizes to suit various diameters, is used.

CANADIAN SYSTEM

The device used in the Canadian method is the one shown in Fig. 111. This consists of a derrick, draw works or machinery

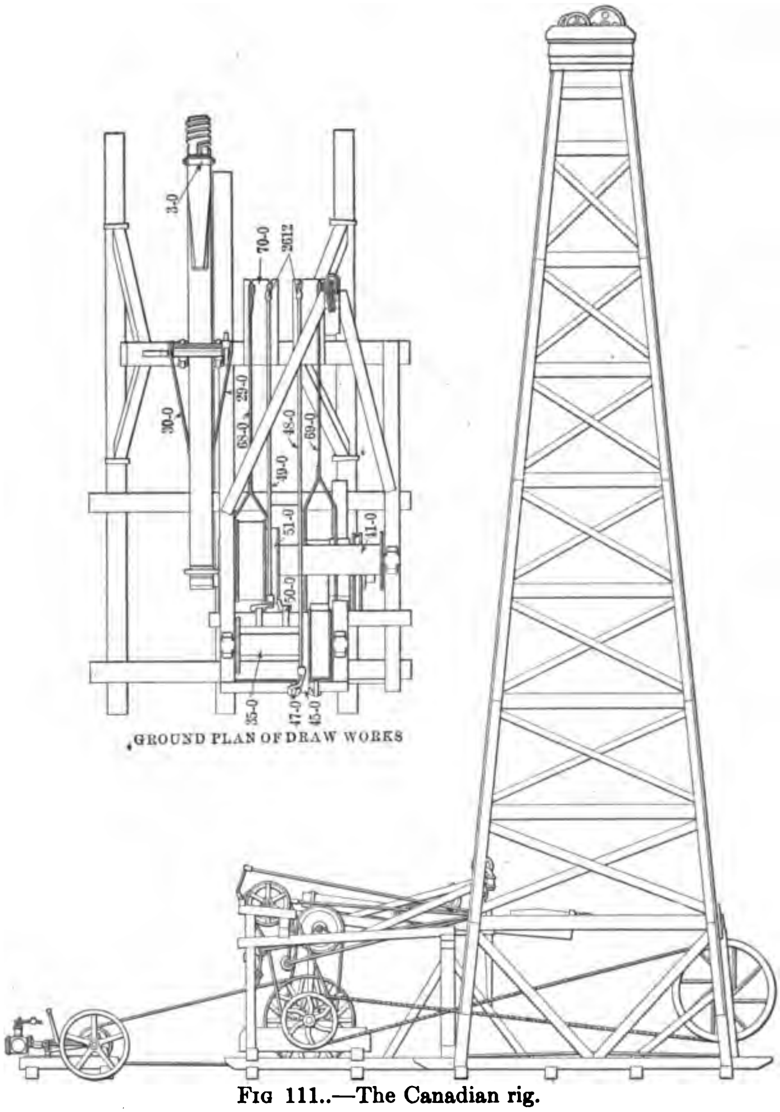

FIG 111..—The Canadian rig.

used to operate the drill, and engine. With this method of drilling, rods are used instead of a cable, as is the case with

the standard or percussion method. The derrick is generally 16 ft. square at the base and 60 ft. in height. The string of tools used with this outfit consists of a socket, jars, auger stem, and bit, the same as used with the cable method. The difference between this and the latter method is that the rods replace the drilling cable and the temper screw is replaced by a ratchet on the walking beam, which ratchet is operated by means of a lever and a chain, as illustrated in Fig. 112. By this means the driller can very easily lower the tools as the occasion requires. This ratchet, or slipper-out, as it is called, is shown in Fig. 113. The chain is shown fitted with a swivel at one end;

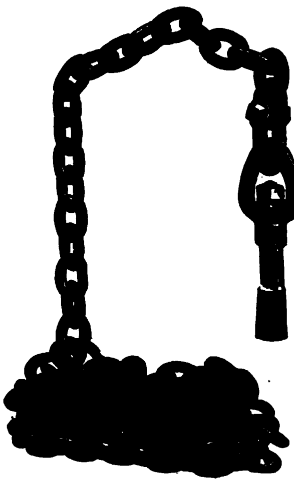

FIG. 113.—Slipper-out, with double dog.

FIG. 112.—Drill chain, swivel and clevis. FIG. 114.—Jacket for spring pole.

this swivel is used in connecting the chain to the drill poles. In Fig. 114 is shown the jacket which slips over the end of the spring pole or beam and around which the chain operates. In this way the weight of the drilling string on the slipper-out is reduced to such an extent that the operator is able to feed or lower the tools at his will. Fig. 111 shows that this method employs a band or drive wheel, as it is termed, and the shaft of this wheel carries a crank having a number of holes, the function of these holes being to obtain different lengths of stroke. This shaft also carries a tug pulley, which, through the medium of the bull rope, drives the bull wheels, the same as in the standard method.

The Canadian or pole tool system is being superseded by the more modern methods, which are much more rapid in operation,[1] due principally to the fact that the tools can be withdrawn from and lowered into the hole much more quickly. When operating with the Canadian system a great deal of time, other than that actually necessary for drilling, is consumed in taking down the drilling string in sections, to replace the bit.

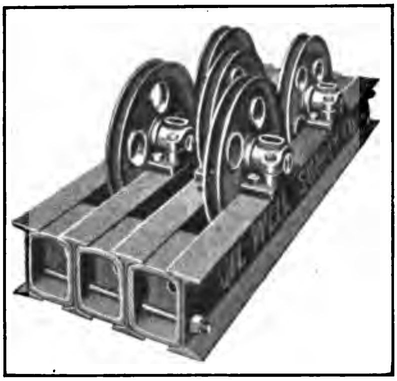

Fig. 115.—Crown block.

HYDRAULIC ROTARY SYSTEM

In certain formations, it is practically impossible to attain any great depth when using the cable tool or percussion method. When this is the case, the hydraulic rotary system is employed. With this system a derrick such as shown in connection with the cable tool method is used. As no drilling cable is used, a crown block such as shown in Fig. 115 is made use of. This block has sheaves all of the same size, as they are used only for operating the casing line in connection with the casing block.

A rotary (see Fig. 116) is used for rotating the drill pipe. A hoist of the type shown in Fig. 117 operates the rotary and the casing line. Two pumps of the design shown in Fig. 118 are employed to prevent the caving of the walls of the hole. Power is obtained from an engine as illustrated in Fig. 119.

[1] The Canadian pole system of drilling is used almost entirely in Galicia, the hydraulic system being forbidden by the authorities, who believe that this method is likely to drown out the oil strata.

In this method a number of lengths of pipe are screwed together, and attached to the bottom of this string is a bit. In cases where rock is encountered for comparatively short distances, a bit (see Fig. 120 and Fig. 121) is used. This bit has rotating cones which are lubricated. As there are a great number of

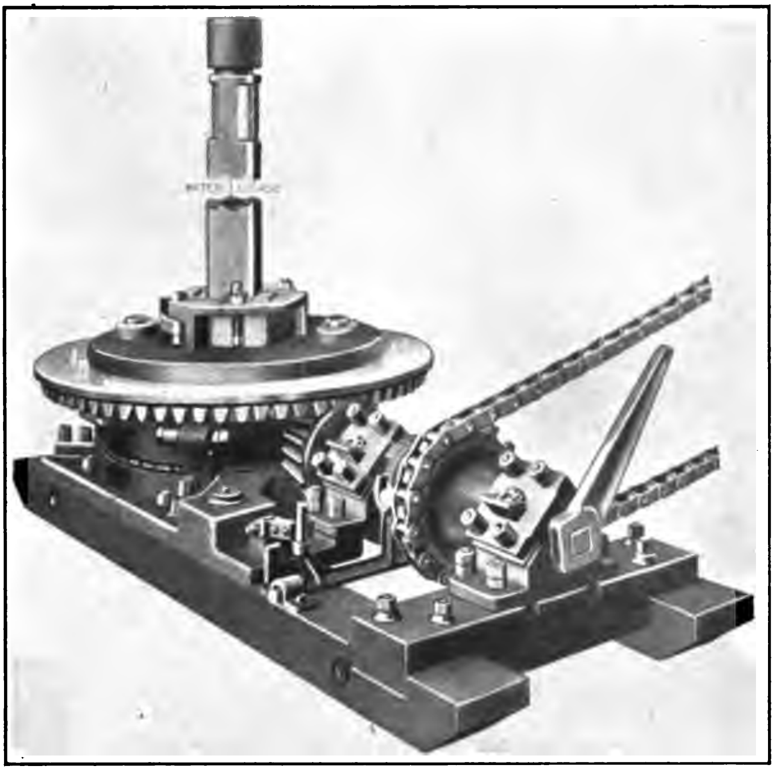

FIG. 116.—Steel rotary with square drill stem.

cutting edges, considerable speed is made through very hard rock.

By a chain driven by a sprocket on the line shaft, the rotary is operated, rotating the pipe. It is to be noted that the top section of the drill pipe is of square cross-section, while the rest of the drill pipe stem is round.

A mud mixer (Fig. 122) is used for mixing the mud. When properly mixed, this mud is emptied into a sump, into which the suction pipe of the pump extends. The mud from the sump is

pumped through the stand pipe shown leaning against the side of the derrick, then down through the hose and the swivel (which

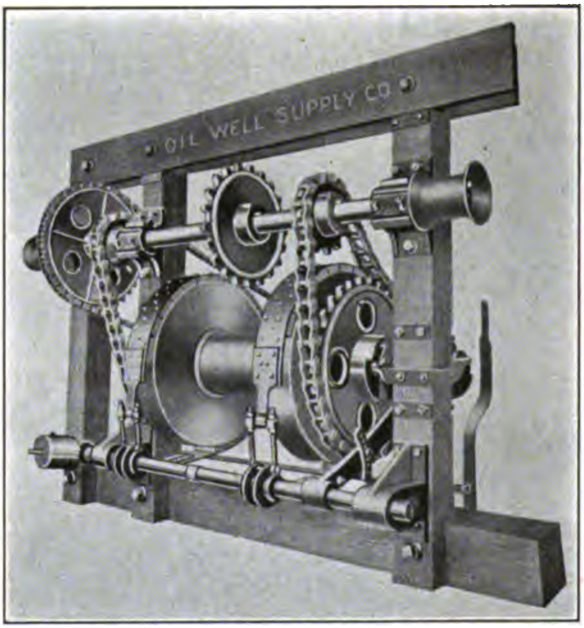

FIG. 117.—Hoist for operating the rotary and the casing line.

is connected to the top of the drill stem) through the drill stem, and returns on the outside of the drill pipe. When it arrives at

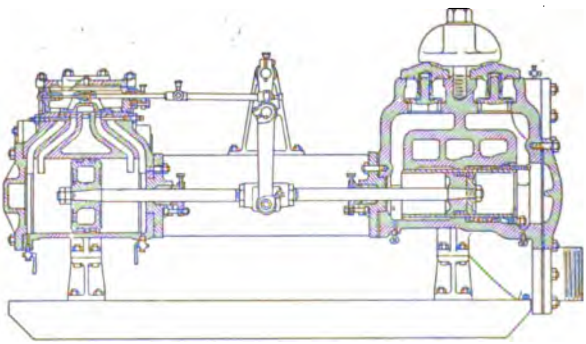

FIG. 118.—Pump used to prevent the caving of the walls.

the surface, it passes through a flume and back into the sump. The object of this flume is to allow sand held in suspension

to settle, so that it can be readily removed. The swivel is shown in Fig. 123 and Fig. 124. The construction is such as to permit

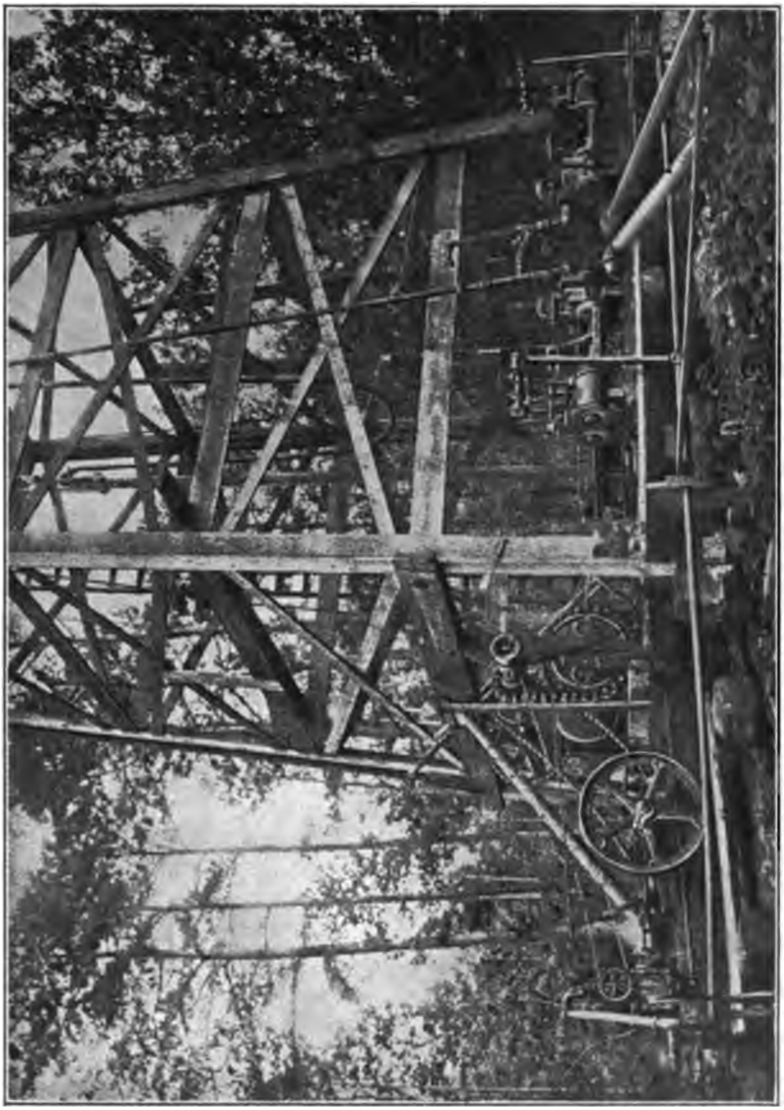

FIG. 119.—The connections from pump to rotary swivel.

of the free entrance of the mud to the drill pipe and at the same time to ensure the rotation of the drill pipe without causing any twisting of the hose or casing lines. This free rotation is

accomplished by means of bearings (Fig. 124) which operate in an oil bath.

Figure 125 shows by the arrow the course taken by the mud as it is passing through and returning outside of the drill pipe. This figure also shows, a back pressure valve located in the lower part of this drill pipe. This valve is used for the purpose of pre-

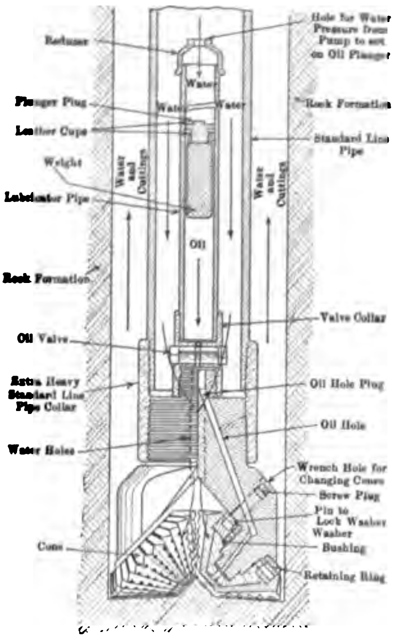

FIG. 120.

FIG. 121.

FIG. 120.—Bit employed where rock is encountered for comparatively short distances.

The bit, line pipe and lubricator are shown in the hole ready for drilling. The lubricator pipe, which is about 12 ft. in length, is filled with special bit oil, which is forced down into the bit under pressure of the water above the plunger.

FIG. 121.—The Sharp and Hughes cone, showing the sixty or more rows of cutting teeth.

venting the plugging or filling up of the pipe adjacent to the bit. Very often, when high gas pressure is encountered, material is forced up through the ports in the shank of the bit and will plug the pipe, providing no such means as a back pressure valve is employed. With the back pressure valve this is not possible. The action obtained by the rotary method is that the mud, in

returning outside of the drill pipe, plasters up the walls of the holes and prevents caving. The plastering is perfected to a great extent by the pipe, when rotating, striking the sides of the hole and causing the mud to impregnate the caving strata. These walls will hold up and prevent caving for a time sufficient to enable the operator to remove the drill pipe and set the desired

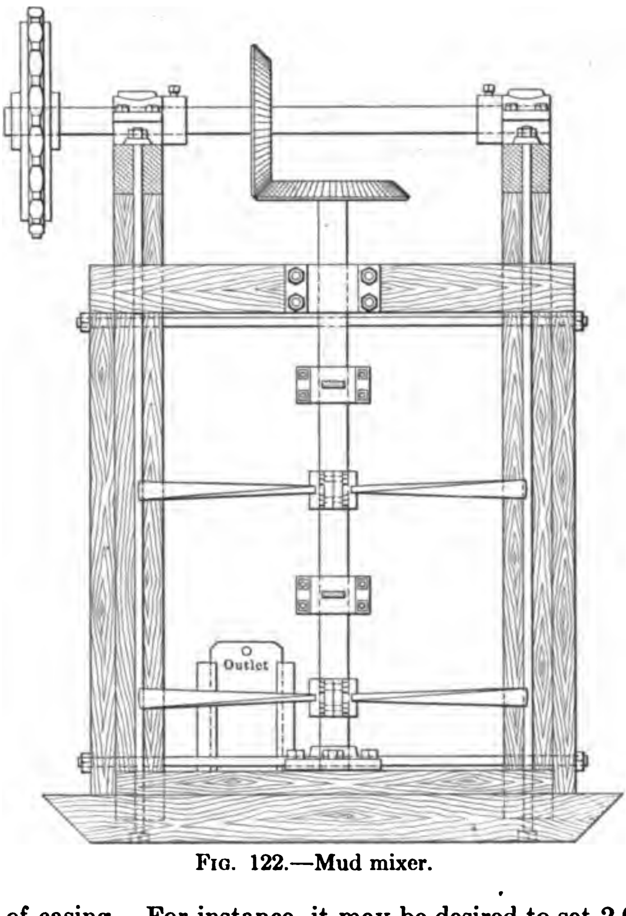

FIG. 122.—Mud mixer.

string of casing. For instance, it may be desired to set 2,000 ft. of 10-in. casing and we will assume that 15½-in. casing has been set at 300 ft. A bit dressed out so that it will freely pass through the 15½-in. casing is used and 1,700 ft. of open hole are made. When this amount of hole has been drilled, the bit and drill stem are removed and the 10-in. casing is inserted, providing the opera-

tor does not consider it necessary to ream out the hole before running in the 10-in. casing.

Occasionally, when drilling through rock formation, a core barrel of the type shown in Fig. 126 is used. When using the core barrel, "adamantine" or chilled shot are thrown into the hole

Fig. 123.—Hydraulic rotary swivel.

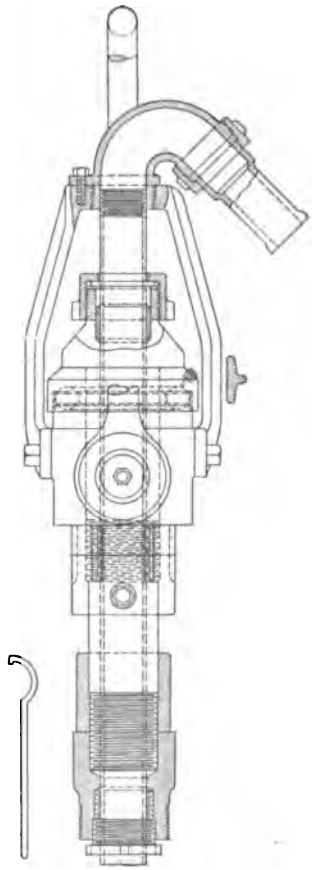

Fig. 124.—Hydraulic rotary swivel.

and rotated upon by the barrel. This action results in the cutting out of a core such as shown in the figure. The core is readily removed by using an overshot or by dropping small particles of iron into the hole, so that they will force themselves in between the core and the barrel itself. Then, by elevating the barrel, these particles become wedged and the core is re-

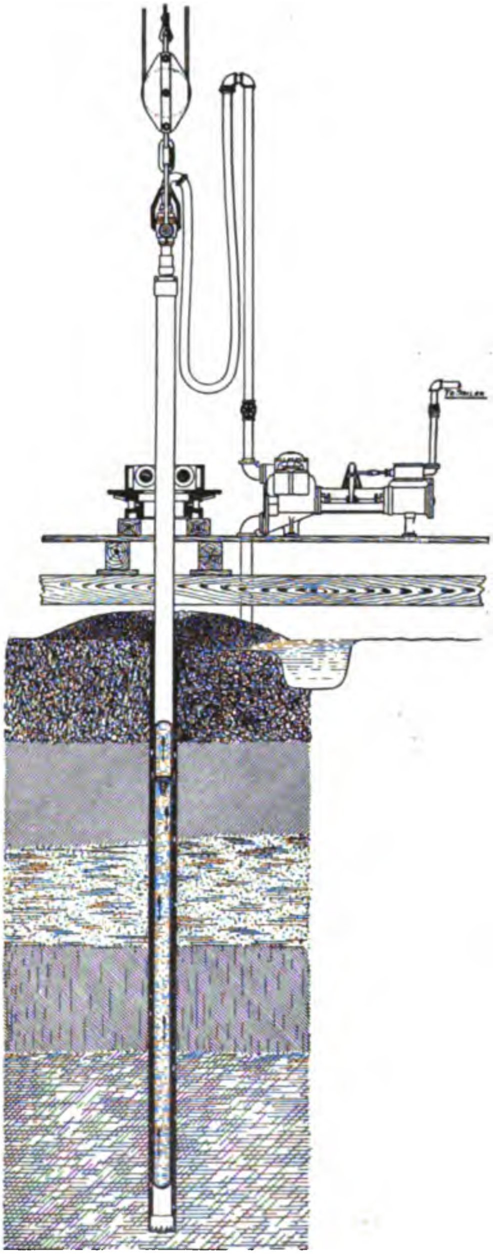

FIG. 125.—An illustration of the method of supplying water to the rotating cutter.

FIG. 126.—Section of drilling well, showing core barrel.

moved. In other cases where hard rock is encountered, a drag bit (Fig. 127) or a drag shoe (Fig. 128) is used. These tools also operate on adamantine, and, due to the rolling effect, the rock is gradually worn away.

It would appear that considerable time would be consumed in removing the bit from the hole and replacing it for operation; but when pipe is removed from the hole, it is taken out in stands, or, in other words, four or five joints at a time are removed and stood back in a vertical position in the derrick. This means that every fourth or fifth joint must be unscrewed, and, to eliminate all possible delay, a tool joint is inserted between the fourth and fifth or fifth and sixth joints of drill pipe, as the case may be.

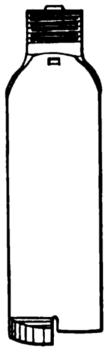

Fig. 127.—Drag bit.

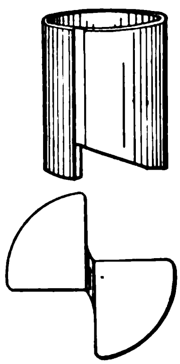

Fig. 128.—Drag shoe.

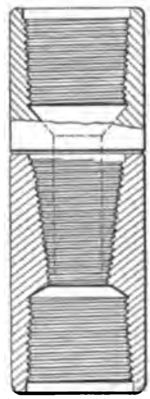

Fig. 129.—Rotary tool joint.

Such a tool joint is shown in Fig. 129. This joint is made in two parts: the upper part being a pin connection, is screwed on to the bottom of the lower joint of stand; the other part of the tool joint, known as the box end, is screwed on to the upper end of the pipe which is being removed from the hole. With this joint it is very easy to remove the casing, as a cat-head on the line shaft of the hoist is brought into play. In order to unscrew one of these joints, back-up tongs are placed around the box end and another set of tongs are attached to the pin end. A rope connected to the tongs is wound around the cat-head, and, as the latter revolves, the joint is broken (started to unscrew). The line to the cat-head is now removed, as well as the tongs on the pin end of the joint; small tongs are attached to the pin end of the joint or

pipe above it, and a very few turns are required to disconnect the joint.[1]

COMBINATION SYSTEM

In localities where it is desirable to bring into play the combination of the cable tool and hydraulic rotary systems, the operating mechanism is located as shown in Fig. 130. With

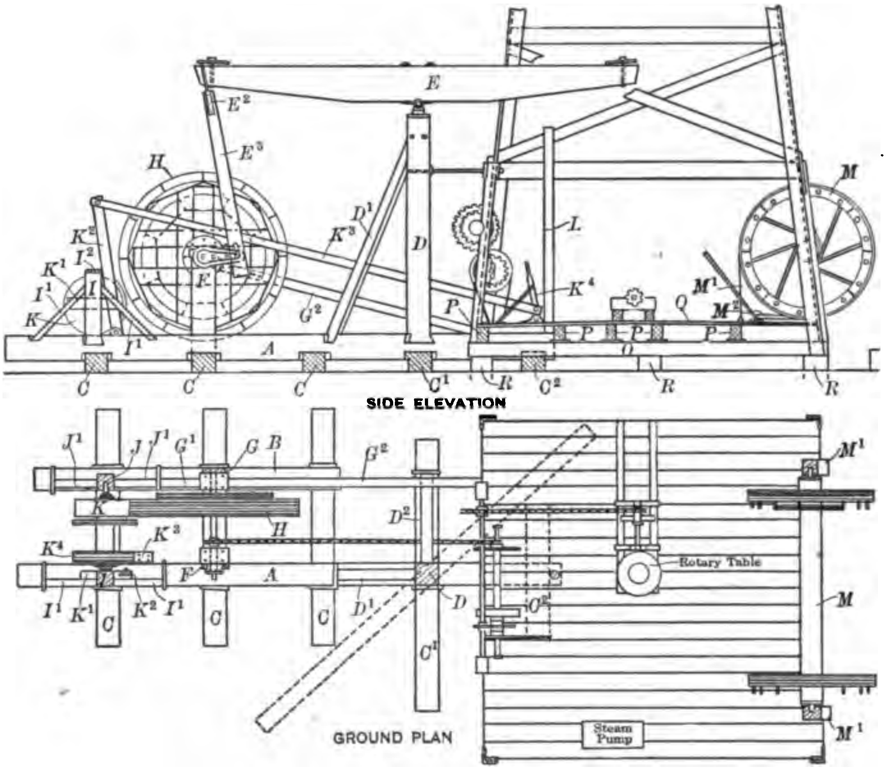

FIG. 130.—Combination rig.

this system the same material is used for carrying on operations as with the cable tool system, with the exception that the calf wheel is replaced by means of draw works and hoist. This line shaft is operated by means of a chain drive from a split socket on the band-wheel shaft.

[1] On rotary well drilling, see PARSONS, *Western Eng.*, **1** (1912), 450; and REA, *ibid.*, 202. On mud-laden fluid applied to drilling, see *Technical Papers* **66** and **68** of the *Bureau of Mines.*

Figure 130 shows the beam swung at an angle so as to permit of the unobstructed spooling of the casing line on the hoist drum. The swinging of this beam, as shown in dotted lines, is accomplished by installing on the samson post revolving center irons, such as shown in Fig. 131. By referring to this it is readily seen that, by merely lifting the latch, the beam is allowed to swing out of the way; and, when the beam is to be operated, it is swung back in line with the samson post and at right angles to the band-wheel shaft. When swung in this position, the latch falls back into the groove, as shown in the above-mentioned figure. The rig shown in Fig. 130 can be operated either as a rotary or cable-tool drilling rig. The time required to change over from

FIG. 131.—Revolving center irons for combination rig.

the rotary to the cable-tool system is only that necessary to lift the rotary away from the hole, which is accomplished in a very few minutes. The hoist then takes the place of the calf wheel.

HYDRAULIC CIRCULATING SYSTEM

The hydraulic circulating system has been used in places where it was desirable to carry on the cable-tool operations, but, at the same time, to use mud for the purpose of holding up the walls of the hole. Such a system is presented in Fig. 132.

The only difference between this system and the cable-tool system is that a circulating head is attached to the casing which is being placed in the hole and closely follows the progress of the bit. By means of this circulating head, mud is pumped through a hose down through the casing, out the bottom, and up along the sides of the hole.

With this method it is not necessary to do any bailing, as all cuttings from the hole are removed by being carried in suspension with the mud forced down by means of pumps. Through the circulating head a barrel or plunger operates and at the top of this plunger is a stuffing box; this prevents the mud from returning through the head or through the barrel. This method of operation is exceedingly slow, due to the fact that it is necessary to follow the bit quite closely, so that there will be sufficient pressure of mud to remove the cuttings. It has, however, met with considerable favor in California and Mexico.

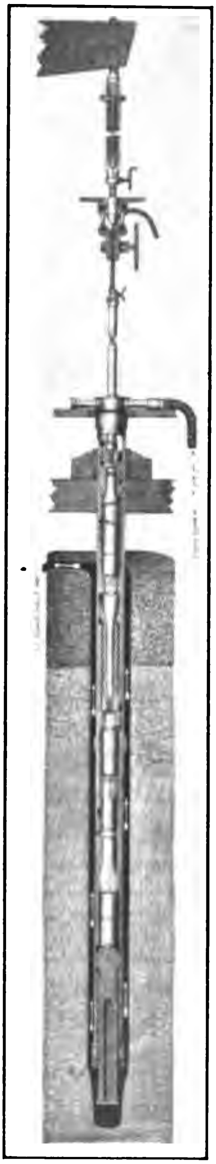

FIG. 132.—Hydraulic circulating system, used in connection with cable tools.

NOTES ON GENERAL DRILLING OPERATIONS

Conductor Box.—In certain localities the surface material consists of loose sandy clay, sand, and gravel, varying in thickness (especially in the Pennsylvania oil regions) from a few feet on the hills to several hundred feet in the valleys. For the purpose of restraining this material, which would otherwise impede the work of drilling, a conductor box, built of plank, circular, square, or octagonal in shape, and 8 in. to 20 in. across, is sunk to the bed-rock. In cases where the rock lies only a few feet below the surface, the necessary excavating is done by hand; but if the soil is deep, a large drilling bit is used to spud down a hole, into which the conductor box or a section of large iron pipe may be sunk as rapidly as drilling proceeds.

Drive-pipe or Conductor.—In starting a well it is customary to extend a "conductor" or "drive-pipe" from the surface to as great a depth as can be driven by ordinary driving methods, through the superficial formations to the solid rock. At one time use was made of a wooden

conductor constructed of planks, but at present the metal drive-pipe is employed almost exclusively. The ordinary sizes of the drive-pipe are 10, 8, 6, and 4½ in. in diameter; the length varies greatly, being in some places as much as 100 or 200 ft., while in other localities the solid rock comes to the surface and consequently no pipe line is required.[1]

Casing.—The casing of an oil well is not, properly speaking, equipment used in its construction, but forms a part of the material which is used up in sinking the well; in other words, the rig machinery, rig and drilling tools may be used again in sinking some other well after the completion of the first, while the casing becomes a part of the well and is never used again, unless the well is a failure, in which instance it may be pulled out and used in another well. While the principal object of the casing is to exclude water which is encountered in the upper strata penetrated, it is also of service in preventing the caving of soft formations. In most deep wells, casing of several different diameters is used: larger sizes are put in the upper part of the well and smaller sizes are used successively with depth.

The methods of casing vary somewhat according to the different methods of drilling; but the general principles are substantially identical, namely, that when a strong flow of water or dry caving formation is encountered, a casing should be inserted to line the well just as soon thereafter as a hard stratum can be reached in which the casing can be set. When once a casing has been set in a formation firmly to shut off the overlying water, it is then possible to drill deeper with a bit of smaller diameter until a deeper water vein is encountered, when a second string of casing is required, which will necessarily be of smaller diameter than the first.

Since the nature of the formations penetrated by the well varies, not only in different fields, but in distinct areas in any one territory, it is, moreover, out of the question that uniform methods of casing wells should prevail. To illustrate, the strata overlying the oil beds in some of the Russian fields are so incoherent that only comparatively shallow depths can be attained before the casing is frozen; it is therefore customary to start a well of large diameter, a 40-in. hole not being uncommon. The opposite conditions are encountered in certain oil fields in the eastern

[1] "Petroleum and Natural Gas Resources of Canada," by F. G. CLAPP and others, *Rept.* No. **291** (1914, **1**), *Canada Dept. of Mines, Mines Branch.*

United States, where it is possible to drill 2,000 ft. or more without the necessity of lining the well, except to exclude the water before tapping the oil-bearing beds. Somewhat similar conditions obtain in parts of the Mexican oil fields where the wells pass through about 2,000 ft. of practically impervious shales. The conditions which prevail in California and in some of the Gulf Coast fields may be said to represent an average between those existing in Russia and the eastern United States, it being necessary to line the hole as drilling progresses, but with less difficulty than in Russia; in this way it is common practice to carry a 10-in. hole for over 2,000 ft.

In drilling for oil it is the aim of the operator to tap the petroliferous beds with a well not smaller than 4 in. in diameter; but it may be said in general that wells finished with 6 or 8-in. casing are operated more satisfactorily than with the 4-in.

Oil-well casing is manufactured in two general ways: (1) from plates 2 or 3 ft. in length, lap-riveted to diameters from 12 to 20 in.; and (2) in lap-welded sections 20 to 40 ft. in length and from 4 to 16 in. in diameter. The latter represents the average American practice. The Russian wells are lined with casings of considerably greater diameter.[1]

Riveted Casing.—Riveted or stovepipe casing is manufactured from No. 8 to No. 12 steel plates in 2- to 3-ft. lengths, from 12 to 20 in. in diameter. In order to construct a string of these short tubes, two separate columns are necessary, one fitting tightly inside the other, so that the joints between the tubes of one column come in the middle of the tubes forming the other; these columns are riveted together in lengths from 10 to 20 ft. before insertion in the hole.[2]

"Stovepipe" is used for lining the first few hundred feet of hole for the purpose of withholding the loose surface material.[3]

Screw Casing.—After the stovepipe has been landed, the wells are lined with wrought iron or steel, lap-welded casing. This is

[1] ARNOLD and GARFIAS, *Report* No. **291,** *Canada Dept. of Mines, Mines Branch,* 1 (1914), 229.

[2] In order to obtain a better bond between the pipes they are indented by hammering with a pointed sledge.

[3] This casing, owing to its smooth outer surface, penetrates more readily the gravel and coarse sediments generally encountered near the surface, and its freedom from screw joints makes it adaptable to heavy driving; the absence of screw joints, however, precludes the easy removal of a complete string of stovepipe, and it is usually left in the well or only partially taken out.

made in 20- to 40-ft. lengths, 2¼ to 16 in. in diameter, threaded at both ends and coupled by a threaded collar.[1] The collars at both ends are provided with smooth recesses which fit tightly around the casing, thus affording greater rigidity to the string.[2] When one considers that the most frequent casing trouble in incoherent formations results from weakness of the joints, the importance of a rigid and strong bond between casing and collar becomes obvious.

Occasionally it becomes necessary to employ screw casing that will stand heavy driving, when the couplings are made so as to allow abutment of the joints. The use of this drive pipe is only resorted to when it is thought that its withdrawal is not important.

Every string of casing is usually provided with a shoe at its lower end to facilitate its insertion and to prevent damage. This shoe is riveted to the stovepipe and screwed to the lap-welded casing; the toothed shoe is claimed to be a great improvement over the plain type.

Pulling Casing.—After the casing has been in a well for a time the formation settles around it, sometimes causing its removal to be attended with difficulty. If it cannot be pulled out in the ordinary way with blocks and lines, hydraulic jacks are used; and if the bottom of the casing will not yield to the pressure of the jacks, it is generally parted, the upper portion being pulled out. If a collar is left on the casing in the hole, a steel die is attached to the collar and the casing is then pulled out; it is lowered again and the die is firmly screwed into the casing below.[3]

Squibbing the casing with nitroglycerin[4] is a quicker and less ex-

[1] The California standard thread for screw casing is ten to the inch and from 3 to 3½ in. in length.

[2] During the last two years the manufacturers have put on the market casings provided with extra long collars with a deep recess at each end.

[3] If the collar is pulled off the casing left in the hole, a steel collar with cutting dies is sent down and is firmly screwed on to the casing. A casing cutter is then sent down on a string of tubing and the casing is cut off where it is thought the obstruction is holding it. If the first cut does not release it, it can be cut again and again, each time higher up, until it is released.

[4] This may be accomplished by filling a small tin tube with nitroglycerin and attaching this tube to a wire line with a firing head attachment; on the bottom of the tube a piece of stiff V-shaped wire is attached, the points coming up on either side of the tube and extending to the casing. The points drag along the casing while the squib is being lowered. When the

pensive way to loosen it when there is no water in the casing to damage it by the explosion.

The size of the hole is always governed by the contemplated depth of the well and by the anticipated difficulties to be encountered. In wells drilled in undeveloped territory sometimes an 18-in. hole is started and this is drilled below the surface sands, which may contain water. Casing 16 in. in inside diameter is then placed in the hole and all water found to this level is shut off. The hole is continued 16 in. in diameter to other water sands and casing of 12½ in. inside diameter is inserted. It is again continued 12½ in. in diameter to another objective point, when casing 10 in. in inside diameter, 45 lb. to the foot, is inserted; the 10-in. hole is then continued through the deeper water sands or cavey formation, when casing 8¼ in. in inside diameter, weighing 24 lb. to the foot, is inserted; the hole 8¼ in. in diameter is then continued, usually to the top of the oil producing sand, when casing 6⅝ in. in inside diameter, 17 lb. per foot, is put in, which shuts off all cave and water found above the oil-bearing sand. If, however, other difficulties arise and it is found necessary to use additional casing, casing 5$\frac{3}{16}$ in. in inside diameter, weighing 13 lb. to the foot, is put in.

According to present practice, in the event that any of the strings of casing placed in the hole have not reached a sufficient depth to exclude water or caving as anticipated, the casing is pulled up 8 to 10 ft. from the seat upon which it rests, and is suspended from clamps which securely hold it at the mouth of the hole; then an underreamer is inserted, and, when it passes out of the lower end of the casing in the hole, it expands sufficiently to meet the wall of the larger hole, and the shoulder or former seat of the casing is reamed so that the larger hole is carried to the point where it is desired the casing should be reseated, in order to shut off water or cave which may have been encountered. The casing is then lowered on the shoulder or seat made by the underreamer.

In proven territory, where conditions are well-known, and after a well has been fully completed and put in producing order, all of

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objective point is reached, the squib is pulled slowly until the points of the wire come to a collar, when they usually catch the bottom of the upper joint of casing and hold the squib; a piece of small pipe through which the wire has passed in lowering the squib is released, and it drops upon the firing head. The explosion which follows separates the casing.

the larger sizes of casing may be pulled out of the hole, leaving the inside string to shut off all water and cave from the oil-producing sand. The casing so removed may be used in other wells and thus greatly reduce the cost of operation.

Packing.—The importance of proper casing cannot be overestimated. A precaution with artesian wells is to make sure that no water escapes between the outside of the casing and the surrounding rock. It is customary to prevent such an escape by surrounding the casing just above the water-bearing stratum with a seed-bag, *i.e.*, a bag made of leather or rawhide and filled with dry flaxseed, which absorbs the water and, by swelling, expands the bag so as to shut off all escape of water outside the pipe. Another method of excluding water is by means of rubber discs.

In order to prevent the entrance of water into an oil well, the casing is set as tightly as possible on some tight rock below the point at which the water would enter. A small amount of water may enter at this point without doing serious damage, provided the pressure of the oil is strong and flushes invading water to the surface. Frequently, however, the amount of water which would thus enter is so great as to require a special operation known as packing. The water from casing wells should always be packed in as completely as possible, otherwise it will accumulate in the well and frequently, by hydrostatic pressure, stop the flow.[1]

Patent Packers.—A packer in general use is made of two metal cylinders with rubber between, 1 or 2 in. thick and varying in length. Such a packer is lowered into the well by lengths of pipes to the position it is to occupy, when a weight is dropped into it which relieves a string, causing the two cylinders to approach and bulge the rubber out into the space to be filled. If water is to be excluded from the bottom of the hole, the packer consists of a rubber plug with a tapering hole; the top mandrel of wood or iron is driven into the block, and expands the rubber to fit the wall of the well and shut off the water below. It has been stated that the wells at Bow Island are packed with a lead packer to keep out water from below; two of these wells penetrated strata containing salt water and had to be packed.

[1] In the early days of oil exploration, a bag of flaxseed was sometimes inserted at the point where the casing was to be set; the seed swelled rapidly, closing the cracks between the end of the pipe and the rock. In other cases the bag of flaxseed has been placed around the casing where it was desired to fill the crack between the casing and the wall of the well. Cf. section on cementing, p. 336.

Screening.—Where wells are sunk in fine sand, a screen must be used which will permit water or oil, but not sand, to enter.

In the Texas oil fields the screens or strainers are generally ordinary pipe, with perforations usually 2 to 6 in. apart; the pipe is then wrapped around with iron wire. If the sand is fine, the wire is wrapped close; if it is coarse, space is left between successive windings. Sometimes the casing is perforated with slotted holes after being set.

Patented strainers are also in use. Some makes, like the Layne strainer, differ from the shop-made ones in the shape of the wire used; the wire has a triangular section and presents a narrow surface to the sand, thus reducing the clogging of the screen, and ensuring greater production and a longer life to the well.

Capping.—This operation consists in placing a gate on the tubing or casing and shutting in the well.

If, in drilling a gas well, a volume greater than 35,000,000 cu. ft. daily capacity is anticipated, and the conditions of the well are favorable for casing to be used in place of tubing, a gate is screwed on the casing and the size of the drill or bit is reduced just before drilling into the gas vein. If reducing the size of the bit is objectionable, a swedge nipple and a gate one size larger than the casing are used.

The Control Casing Head.—A new device intended to safeguard the drilling of wells has been introduced by A. G. Heggem and is now in use in the principal oil fields of this country. This is known as the control casing head and is, in fact, a practical oil-field valve so designed as to include all of the functions of a casing head.[1]

The body portion is approximately the size and shape of a T casing head, although much heavier in construction, as the control casing head is built to withstand a working load of 1,800 lb. per square inch. A round valve within the body may be turned to close either top or bottom opening or to leave both open, thus deflecting the flow into the flow line or shutting in the well entirely or forming a free passage for the drilling tools the full size of the casing. The peculiar features of design are that the pressures are nearly counterbalanced and the valve turns easily in service. The valve may be closed tightly, even though a rope or cable passes through the casing head, and thus the well may

[1] On the control casing head, see HEGGEM, *Bull. Am. Inst. Min. Eng.*, **1916**, No. **109**, 151.

be brought under instant control and all oil or gas saved without withdrawing the tools or injury to the drilling line.

It is claimed that with casing properly seated and anchored and with a control casing head on the inner string, all drilling operations are under control, and losses of life and property through fires and "blowouts" are thus minimized.

COST OF DRILLING

There are few engineering operations in which the daily rate of progress is as variable as that of sinking a well. The material which the drill has to penetrate often consists of very dissimilar strata, changing in character with every 2 or 3 ft. drilled, and the angle at which the strata dip is also an important factor. Then, too, the breakage of tools, which cannot be foreseen, may involve the loss of many days. It is consequently difficult, even where the geological conditions are known, to say what may be regarded as a fair daily rate of drilling.[1]

When, however, several wells have been sunk on a certain property, and oil has been obtained at about the same depth, it is possible, if accidents are excluded, to predict with a fair degree of accuracy the time occupied in sinking a well. In a large number of cases, wells have been put down with great regularity, and the producer has been thus enabled to calculate closely the cost of each well; but in operating in another district, he has, as a rule, found the data obtained from his previous experience of little guidance. It must not therefore be assumed that because a certain number of wells have been drilled in one district, in a given time, and at a stated cost, or at an average cost of so much per foot, similar results can be achieved in a new field where the conditions may be very different.

Table XXXVII, shows in some cases the usual total cost of drilling in established fields and in others the price per foot.

As a rule, in the Ontario field the thrift of the oil industry is said to be much more advanced than it is in some of the fields of the United States. While wells in certain of the large fields of the United States have been abandoned, sometimes in cases where

[1] For a consideration of the factors in the cost of oil production, see Jewell, *Min. Sci. Press*, **103** (1911), 44. On the comparative costs of rotary and standard drilling, see Requa, *Bull. Am. Inst. Min. Eng.*. **1915**, No. **98**. 217.

TABLE XXXVII.—COST OF DRILLING WELLS

Locality	Standard method	Canadian method
United States		
Gaines, Pa.	$0.65 per foot	
Summerland, Cal.[1]	0.85 per foot	
Northern Mississippi Valley	0.75 per foot	
Eastern Washington	2.50 per foot	
Texas: Beaumont field	4.00 per foot	
Caddo, La.	$12,000.00	
Canada		
Brant County:		
Brantford fields		
Onondaga fields		$800.00
Ontario:		
Petrolia		160.00
Bothwell		500.00
Haldimand County:		
Carlow	700.00	
Simcoe:	1.35 per foot	
Port Rowan	2,900.00	
Northern Alberta:		
Pelican		25,000.00
Central Alberta:		
No. 2 Tofield	9.50 per foot	
No. 3 Tofield	7.50 per foot	
Vegreville	9.00 per foot	
Wetaskiwin	10.00 per foot	
Southern Alberta:		
Medicine Hat		7.25 per foot for 10-in. hole. 6.50 per foot for 6-in. hole.
Brooks Station		40,000.00
Lethbridge		10,000.00

[1] The cost of drilling wells in California differs greatly in various fields and even in different parts of a single field. The following table illustrates the variation and emphasizes the fact that general statements are useless.

APPROXIMATE DRILLING COSTS PER FOOT FOR DIFFERENT DEPTHS AND FIELDS

	1,000 ft.			2,000 ft.			3,000 ft.		
	Labor	Material	Total	Labor	Material	Total	Labor	Material	Total
Coalinga	$2.02	$9.68	$11.70	$2.34	$9.15	$11.49	$1.90	$9.18	$11.08
Kern River	1.90	5.00	6.90						
Midway, Sunset and McKittrick	1.16	6.40	7.56				2.48	8.38	10.86
Santa Maria							1.69	2.72	4.41
Ventura	1.54	2.67	4.21						
Los Angeles and Orange				0.78	3.06	3.84	2.22	7.50	9.72

they produced as high as 10 or 20 bbl. per day,[1] wells in the old Ontario fields, on the other hand, are seldom abandoned until the production falls to a few gallons.

In Ontario, in the early days, it naturally took a long time to put down a well, as the methods were crude as compared with those now in use. In 1868, it sometimes required six months to drill a well. In 1890, however, a hole could be drilled in four or five days at a cost of $160 per well, the owner of the well furnishing the casing. After the well had been completed, the pump was inserted by the driller and the well was then tested for a day. In the Petrolia fields a drilling gang consists of six men, three working in the day shift and three in the night shift. Pole tools are used, consisting of a bit and an iron bar about 3½ in. in diameter, connected with the walking beam above by poles.[2]

Owing to the decline in production and the abandonment of most of the oil wells in Ontario, it has been necessary for the men employed in the contracting and drilling business to seek employment elsewhere. The Canadian drillers are quite expert and have been in demand; they have now moved to all parts of the world, including Germany, Austria, India, Burma, Mexico, Australia, and some have even gone to Pennsylvania.

THE TORPEDOING OF OIL WELLS

When drilling has been completed or when the production is found to decrease, a general practice is to "torpedo" the well

[1] Cf. the conditions in the historic Appalachian oil field, where most of the pools have long since passed their prime, although none has been entirely abandoned and wells are still being pumped in the immediate vicinity of the original Drake well at Titusville, Pa. In New York and Pennsylvania, production is kept alive mainly by cleaning and deepening old wells and by obtaining petroleum from shallow sands which were passed by as too small when oil wells were first drilled.

[2] The cost of sinking an ordinary well in the Petrolia fields in the early days of development was about $1,500. The cost in 1890 had dropped to $150 or $160, which is as cheap as wells can be drilled in almost any oil field in the world, with the exception of Oil Springs, where the depth is 100 ft. less. In the Petrolia field the plan was to drill one to ten oil wells to an acre, and it was supposed by the oil men that if less than four wells to the acre were drilled, the territory had not been thoroughly tested. Wells in the Petrolia field were kept in good condition by occasionally cleaning them, which custom has been followed in recent years. See *Report* No. **291**, *Canada Dept. of Mines, Mines Branch*, **1** (1914), 225. This useful report has supplied much of the information given above. On the development of the Ontario oil fields, see *idem*, **2** (1915), 105–9.

to increase the flow.[1] This procedure was patented in 1862 by Roberts, who entertained a belief which was held by many at that time, namely, that the oil was contained in crevices in the rock, which might not have been tapped by the bore hole; accordingly he suggested the use of nitroglycerin, gun-powder, or other explosives, to break up the rock at the bottom of the well, so that these rich "pockets" might be brought into communication with the well.

FIG. 133.—Col. E. A. L. Roberts.

For several years Roberts was unable to apply his invention, since oil producers feared injury to their wells; in 1865, however, he was given permission to experiment upon the Ladies' well near Titusville, Pa., and obtained a favorable result. In December, 1866, he exploded a torpedo in a "dry hole" (the Woodlin well) on the Blood farm, and obtained a production of 20 bbl. daily, which was increased to 80 bbl. by the explosion of a second torpedo. The most striking result, however, was in the case of the

[1] On torpedoing oil wells, see ZALOZIECKI, *Naphta*, **13** (1905), 76.

Armstrong No. 1 well, at Thorn Creek, Warren County, Pa., which, in 1884, after having been considered a "dry hole," was converted, by a heavy torpedo explosion, into a rich producer.

Regardless of the danger incident to its handling, nitroglycerin is now freely used to stimulate the production of declining wells and is invariably employed in torpedoing new wells when completed where the sand is found to be of a close texture. The

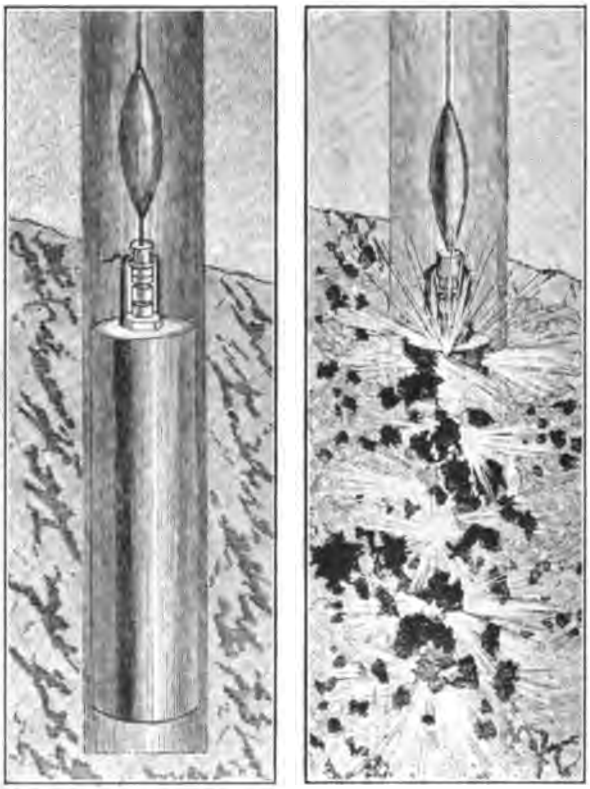

FIG. 134.—The Roberts torpedo, before and during explosion.

amount of explosive used has been increased from the original 4 to 6 qt. to 60, 80, 100, and even over 200 qt. It has been a general practice to place the nitroglycerin in tin canisters of about 3½ to 5 in. in diameter, and up to about 10 ft. in length; these canisters have conical bottoms, and fit one in the other. They are separately filled with nitroglycerin, and are then low-

ered to the bottom of the well, one after the other, by a cord wound upon a reel, until the required number has been inserted.

Formerly the upper end of the highest canister was fitted with a "firing-head," consisting of a circular plate of iron, slightly smaller than the bore of the well, and having attached to its underside a vertical rod or pin carrying a percussion cap. The cap rested on the bottom of a small iron cylinder containing nitroglycerin. To explode the charge, a cone-shaped cast iron, known as a "go-devil," was dropped from the top of the hole into the well, and, striking the disc, exploded the cap and fired the torpedo. Many premature explosions caused a change in this method of exploding torpedoes. The nitroglycerin "jack-squib" is now being generally used. This squib consists of a tin tube, about ¾ in. in diameter and 2 ft. in length. A 3-min. fuse, with a fulminate cap attached to the lower end, is wound around the tube to the top and extends several inches above the tube. The tube and fuse are placed inside of a larger tin tube, about 2 in. in diameter and slightly longer than the inner tube. Dry sand tamping fills the space between the two tubes. The top of the larger or outside tube is turned in and pressed down on top of the sand, keeping it in place. When everything is in readiness to explode the torpedo, the inner tube is filled with nitroglycerin and corked; the fuse is then lighted and the jack is dropped into the hole. The explosion usually follows. It is desirable to have fluid tamping on top of the torpedo. Where this cannot be done, on account of the proximity of the casing to the top of the sand, it is claimed that large torpedoes cannot be used with success.

It has been found in practice that locating the nitroglycerin in the pay sand is of the greatest importance. If the torpedo is allowed to extend above the pay sand, the barren formation shattered by the explosion will subside and cover the pay sand, greatly interfering with the operation and production of the well.

The keen competition among certain producers has been a frequent cause of the use of large torpedoes, with the hope of shattering the pay sand to such an extent as to let the oil come more freely to the hole from a large surrounding area. Where large torpedoes are used in wells with a limited pay sand, the barren formation may become shattered to such an extent as to render the wells valueless.

However, the experienced and conservative producer will not

risk the ruination of his property in this way. If he has a well with 10 ft. of pay sand, which he desires to torpedo, he will place 20 qt. or 66⅔ lb. of nitroglycerin in a shell 5½ in. in diameter and 4 ft. 4 in. in length. An anchor, consisting of a tin tube of sufficient strength to support the weight of the torpedo, and of sufficient length to elevate the top of the torpedo to within 3½ or 4 ft. of the top of the pay sand, is attached to the bottom of the shell. The shell is attached to a line with a hook which releases its hold of the shell when it reaches the bottom of the hole, and, after the torpedo is placed in this way, the operator, to guard against any possible error in calculation, or in danger of some obstruction preventing the torpedo from going to the objective point, will take a steel line measurement to determine the exact location of the torpedo before it is exploded.[1] Should the torpedo be found misplaced, it is fished out of the hole; the obstruction is removed, or the anchor is shortened or lengthened, as the case may require, to bring the shell to the desired place in the pay sand.

When the explosion occurs, the fluid and much shattered sand are usually expelled from the hole. Should the shattered sand settle into the hole made by the explosion, it is removed by the use of tools made for this special purpose. When the hole is thoroughly cleaned, it is usually sufficiently large to admit several torpedoes of the size of the first one used, being placed in the same space in the pay sand.

When the shell of a subsequent torpedo is released from the line which carries it to the bottom of the hole, there being no wall to support it, it falls over in the hole; additional shells can be placed in the cavity, or shot hole, and in this way the size of the torpedo may be greatly increased and at the same time kept in the pay sand.

Shells used in subsequent torpedoes, or where the wall of the hole will not keep them in a perpendicular position, are so constructed that the opening in the top of the shell through which it is filled, can be corked to prevent the nitroglycerin from escaping from the shell.

The Electric Torpedo.—When it is found necessary to case a well near to the top of the pay sand, it cannot be given a large torpedo safely in the pay sand without great danger of damaging

[1] *Report* No. **291** (vol. **1**), *Canada Dept. of Mines*, *Mines Branch*, **1914**.

the casing. In cases of this kind the well is given an electric torpedo, as follows:

The torpedo is placed in the proper location in the hole; a squib containing 2 or 3 qt. of nitroglycerin, attached to an insulated wire, is then lowered to the top of the torpedo. The casing is pulled out of the hole over the wire, and the squib is exploded by a battery and it in turn explodes the torpedo. The casing is again put into the well, the hole is cleaned out and the well is put in producing order.

This method of shooting is only resorted to in newly developed territory where there is good rock pressure. In old territory where the rock pressure is low and where much oil has been taken out of the sand, when the casing is removed, the water and cavings which have been shut off by the casing flood the sand. When the torpedo is exploded, the column of water offers more resistance than the rock pressure of the sand, with the result that the mud and water are blown into the pay sand, and the well greatly damaged and in many cases totally ruined.[1]

Occasionally wells yielding large quantities of petroleum can be improved by torpedoing. This is a dangerous proceeding, which is usually accomplished in the following manner. If the well is flowing by heads, careful gauges of its production are taken, the time between flows and the quantity of oil produced at each flow being noted. When the maximum flow is ascertained in this way, it is known almost to a certainty how much time will elapse before the well will flow again. The torpedo is prepared and the well is watched closely; when it flows, the gauge is taken, and if it has produced the maximum flow, there will then be sufficient time to lower the torpedo safely before the well will flow again. If the well did not make its maximum flow, it will come in again in less than the usual time; and if the well should flow while the torpedo is being lowered, it will be thrown out of the hole with disastrous results.

When a torpedo is safely landed in the pay sand, it will not be thrown out by the flow. The torpedo shooter usually waits for the well to flow, and, while the hole is empty or the oil which has been left in the hole is held in suspension by the gas, the torpedo is safely exploded without damage to the casing.

If a well flows continuously and the production is large, "well enough should be let alone." Such wells should not be torpedoed.

[1] *Report* No. **291**, *Canada Dept. of Mines, Mines Branch,* 220.

If, however, the wells are gassy, and do not produce much oil, and the owner desires to torpedo with the hope of increasing the production of oil, and in the event the gas pressure offers too much resistance to permit the torpedo to be lowered into the hole, a weight sufficient to overcome the gas pressure is attached to the bottom of the torpedo which carries it to the bottom of the hole.

The Petrolia, Canada, wells were shot with 8 to 10 qt. of nitroglycerin, the charge being much smaller than in the Pennsylvania fields, where 80 to 90 qt. are frequently used.

CEMENTING WELLS

The cementing of boreholes for the purpose of withholding or shutting off water has been satisfactorily accomplished in many oil fields.

In a valuable discussion of water intrusion and methods of prevention, Oatman[1] states that as practised in the principal California oil fields, the methods of excluding water may be classed as temporary and permanent. Permanent exclusion may be obtained by forcing the lower end of a string of casing, called the "water string," into an impervious bed above the oil-sand; or by placing a water-tight body of cement between the casing and the formation. Of these two procedures, the first is unsatisfactory and is not considered good practice.

Temporary.—Regular or special well packers may be employed to prevent temporarily the entrance of water until permanent relief can be found. Such packers are useful in wells wherein the casing may be punctured above the oil-sands and water finds entrance to the productive zone through the casing. Bags of flaxseed, peas, or cereals which swell greatly on absorbing water, forming a compact mass, were formerly introduced in wells to exclude the water temporarily, but the cementing method has superseded the use of such palliatives in California.

As a preliminary step to cementing a well in which gas is causing severe agitation, Oatman recommends bridging the hole by ramming in broken stone, earth, etc. A method used by some operators is to place in the hole a generous plug of a composition which has the effect of restraining the gas, temporarily at least;

[1] *Trans. Am. Inst. Min. Eng.*, **48** (1914), 627. On the cementing process of excluding water from oil wells as practised in California, see also ARNOLD and GARFIAS, *Technical Paper* **32**, *United States Bureau of Mines.*

for example, the mixture (parts by weight) composed of 5 parts of red lead, 2½ parts of sand, 2 parts of plaster of Paris, 2 parts of rosin, and sufficient boiled linseed oil to make a dense paste; this mass should be allowed to set in the well about 24 hr. before proceeding with cementing.

Permanent: By the Use of a Drive Shoe.—In sinking a well, a steel drive shoe is attached to the lower end of the casing. This shoe is slightly larger in external diameter than the casing and has a cutting edge. Prior to the introduction of cementing, it was the custom to land the water string in some compact formation located above the oil measures, by forcing the drive shoe into that formation; the well was then continued with a smaller drill, the casing resting on a shelf. This method has been used in some California fields, where certain special conditions obtain, but it is not reliable owing to the fact that water generally leaks past the drive shoe and passes into the well. It may, however, be applied in other fields in which the water string can be landed in an unfractured sticky clay shale.

Permanent: By the Use of Portland Cement.—A search for some means of effecting the permanent exclusion of water resulted in the use of Portland cement.[1] This cement has been employed for several years, and, when properly manipulated, has been found to give the desired result.

The methods in general use for cementing-off water are the tubing, the bailer, and the Perkins. According to Oatman, the object of any cementing operation is to obtain a compact collar of cement which will firmly adhere to the casing and so fill all voids resulting from drilling that no water can descend into the oil-sands. The operator aims to land the string of casing in a compact bed of shale, which is impervious to water and is capable of sustaining the weight of the casing; for example, in the Coalinga field, experience has shown that the blue or brown shale encountered just above the oil-sands provides a most suitable final landing place.

Tubing Method.—The following examples illustrate the tubing method of cementing.

[1] On the cement-lining of oil wells, see Bogouschevski, *Gorn. Jurn.*, **4** (1908), 1–30; and on cementing-off water from oil wells, see Del Mar, *Eng. Min. J.*, **90** (1910), 250; Hager, *Western Eng.*, **1** (1912), 534; Stroud, *ibid.*, **2** (1913), 203; Paine, *ibid.*, **2** (1913), 445; Phelps, *ibid.*, **3** (1913), 360; and Huber, *ibid.*, **4** (1914), 341.

Method A.—At the point where the water is to be excluded the hole is reamed out from 4 to 6 in. larger than the pipe for about 40 to 80 ft. from the bottom. The water string is raised a foot or so from the bottom and water is pumped down inside the casing and up to the surface around the exterior thereof. The purpose of this operation is to effect free circulation; to wash away the mud, oil, etc., from the sides of the casing and the hole, so that cement may adhere thereto; and to open the space around the casing so that a complete ring of cement may form. This water circulation may be continued for a considerable period, sometimes as long as 30 hr. or more, to clean the hole thoroughly. The casing is then raised 2 to 6 ft. from the bottom, and a string of tubing (3-in. standard size), with a swedge nipple on the lower end, is lowered to within about 2 ft. of the drive shoe. A cast-iron disc, or a packer, fitting close to the inside of the casing, is also on the bottom of the tubing; this is to prevent the cement from rising in it. The well is allowed to stand for a period of from 10 to 28 days.

The time of mixing and placing cement varies with the operator. Some companies claim to be able to mix and place all their cement in from 30 to 40 min.; other companies state that they require an hour or more. The element of time is exceedingly important, as the cement must be placed and allowed to settle before the period of initial set has been passed. The amount of cement used varies from 2 to 10 tons, according to the practice of the operator and the requirements of a particular case; but 4½ tons may be taken as the average amount required. The cement is mixed with enough water to make the mixture of the consistency of thick gravy, so that it can be readily pumped. Neat cement is most favored, although a sand-cement mixture may also be used. If sand is to be employed, 10 to 15 per cent. may be added when mixing. For neat cement the amount of water added is about 60 per cent. of the weight of the cement.

Method B.—This is practically the same as Method *A*, but the method of packing the bottom of the casing requires description.[1]

The hole is reamed out and prepared as described above. The water string is raised a foot or so from the bottom and a string of 3-in. tubing is lowered therein. Attached to the bottom of the tubing is a Graham packer, which is constructed of cast iron with outside leather packing and fits snugly against the inside of

[1] Oatman, *loc. cit.*

the casing; it contains a self-closing clack valve, opening downward, and three forked iron strips project from its lower side. The prongs of these forks are compressed and lie in the inside of the casing during descent, but spring out when they pass the bottom of the casing. Then, on pulling up, they hook on to the drive shoe of the casing, and the operator knows that he has reached the bottom of the hole. A wire fastened to the packer keeps the valve open during descent, so that water may enter the tubing. When the prongs are pulled up on reaching the bottom, this wire is broken and the valve closes.

When water or cement descends through the tubing, the valve can open, but pressure from below will close it. On top of and following the cement is a long wooden plug. Water is pumped down, as before, on top of this plug. When the plug reaches the valve it sticks, and the pump pressure rises so that the operator knows that the tube is free of cement. The well is then allowed to stand for the proper period.

There is a left-hand thread between the bottom end of the tubing and the packer. The joints of the tubing have a right-hand thread. To remove the tubing, the string is turned so as to tighten the right-hand joints, which unscrews it at the bottom. When drilling is resumed, a few blows from the bit will break the brittle cast-iron packer into small pieces.

Method C.—This is known as the "top-packer" method. The hole is prepared as before and assurance is had of circulation. The casing is suspended from 2 to 6 ft. above the bottom and 3-in. tubing is run in to within 2 ft. of the casing shoe. A packing head is then placed over the top joint of the tubing and is screwed into the top casing coupling, packing off the space between the casing and the tubing. When the casing is filled with water and cement is pumped through the tubing, it cannot rise inside the casing, but must travel around the shoe and up on the outside.

Bailer Method.—In this method the hole is underreamed for a distance of about 40 ft. from the bottom and circulation is assured. The water string is then raised about 10 ft. from the bottom. The cement is mixed at the surface as before, and is placed in a large bailer arranged with a special trap so that it will dump on reaching the bottom. Usually two loads of a 40-ft. bailer are deposited in the bottom of the hole. The casing is capped and then allowed to drop, forcing the cement up around the casing and into the bottom formation. On opening a tap

and releasing the pressure, the casing sinks to the bottom. It is then spudded into the bedding formation.

Some companies bail the cement out from inside the casing before it sets; others allow the cement to set and then drill down through it when extending the hole. The best practice, according to Oatman, is to bail out the cement if the casing is well spudded into the shale. This dispenses with the necessity of drilling out the cement from the interior of the casing, an operation liable to fracture the cement collar. Instances have been reported where the bailer was tripped while being lowered, but these accidents are rare.

Perkins Method.—The Perkins method, which is similar to the tubing method in results, has been successfully used in the California fields. The following description will serve to explain the operation.

After circulation is assured, a cast-iron packer (*A*) with flexible rubber discs at its top and bottom, is floated in the water filling the casing. The cement is mixed and is then pumped into the casing, forcing the packer down. A leather cup packer (*B*) is placed on top of the cement, and, on continuing the pumping, the charge of cement is forced to the bottom between the two packers. When the lower packer reaches the bottom it stops, while the cement is forced past *A* by the flexion of the rubber discs. All the cement can be thus forced into the hole outside the casing. When packer *B* reaches packer *A*, the pressure rises at the pump and the operator knows that the cement has been placed. Pumping is then stopped and the water string is set on the bottom. The well is allowed to stand for the usual period.

When drilling is resumed, packers *A* and *B* are soon broken by blows from the heavy bit and sinking is continued.

Discussion of Cementing Methods.—The success of all cementing methods is dependent upon the fact that cement grout is heavier than water and consequently displaces the latter. There should, according to California experts, be a long collar of cement around the casing, no matter which method is used, and this cement collar should extend some distance up the casing.[1] The tubing and Perkins methods have one advantage in that the large amount of cement used coats the casing for

[1] In some cases the cement runs up for only 25 ft. to 40 ft. Instances have been known where it has been forced 400 ft. or more above the shutting-off point.

some distance above the bottom of the hole. As this coating may be through the water sand, the cement is believed to form an effective protective coating against the deterioration of the casing by ground waters. The corrosion of casing by chemically active waters, resulting in the passage of water to the oil-sand, is a very dangerous condition in the oil fields. This is, in fact, a very strong point in favor of tubing or similar methods.

Following the hardening of the cement, the well is bailed dry. If there are no leaks at the bottom, or through holes in the casing, a dry well should result, and drilling may be resumed. If unsuccessful, the hole should be recemented. It may be mentioned here that cases are on record where it has been found necessary to recement two to eight times.

Either the tubing or the Perkins method is said to be applicable in the average case. The bailer method may be used in normal cases, and also when it is necessary to block some hole already existing, or in closing a discarded hole. The drive-shoe method is applicable in a compact sticky shale unfractured by heavy drilling. One of the large California companies claims to have wells in which the water was successfully excluded by use of the drive-shoe method 10 years ago, and which are still water-tight, but such cases are exceptional.

Because of the rapid corrosion of pipe in many California fields, due to the action of water, it is of the highest importance that, as far as possible, a thick coating of cement surround the water string. Many present-day operators are advocating the following operation for permanent protection against water intrusion. Sink the 12-in. casing as far as practicable and then cement off by the tubing method, forcing the cement as near to the surface as possible. Then land the 10-in. water string in a suitable bed above the oil-sands, cementing again by the tubing method and forcing the cement well up around the pipe. Run in a string of 6-in. casing, land it 2 to 4 ft. below the 8-in., and cement the space between the 6-in. and 8-in. solid. In this case the bottom of the 6-in. is only a few feet below the 8-in. and is in the same impervious shale bed. If this method is adopted, the second water string is protected by a heavy ring of cement, and, if properly done, the well should last for many years. Oatman predicts that this method, or a modification thereof to meet special circumstances, will inevitably be adopted in California to meet the demand that absolute, permanent exclusion be secured.

The operation of cementing oil wells has been fully described by I. N. Knapp,[1] who maintains that all ground water, oil and gas may and should be excluded from a well before cementing. Knapp's paper should be consulted for a detailed explanation of how to bring a well into condition for cementing.

The California State Mining Bureau has supplied the following data on actual operations.[2]

A convenient size of mixing box is 10 ft. by 20 ft. by 1 ft., allowing several men on each side to mix with hoes as the cement and water are added. Ordinarily from 7 to 10 gal. of water per 100 lb. of cement are used, making a readily flowing mixture, about the consistency of cream.

Two pumps of the "Gumbo Buster" type should be connected, in case an accident should disable either one. Pressure of 600 or 700 lb. per square inch is frequently necessary to start circulation, which is only continued until a free passage is assured and not until all mud is removed, which might cause the hole to cave and "freeze" the casing.

Various cements on the market have been shown to be of about equal value, providing initial set occurs within 3 or 4 hr. The amount used, according to R. D. Bush, is about as follows:

Depth, 1,000 ft. to 2,000 ft.	
10-in. casing with 500 ft. to 700 ft. friction	5 to 7 tons
10-in. casing with 100 ft. friction	1½ to 2 tons
Depth, 2,000 ft. to 3,500 ft.	
8¼-in. casing with 500 ft. to 700 ft. friction	3 to 5 tons
8¼-in. casing with 100 ft. friction	1 to 2 tons

In two known instances 10-in. casing was ripped out and 5 tons of cement were found to have filled the space for about 180 ft. from bottom. Both wells were drilled by cable tools with little or no reaming.

An estimate of cost, aside from the regular drilling crew, is as follows:

Inserting and pulling tubing, 2 extra men, 5 hr.	\$3.50
Hauling cement	5.00
Hauling box and pump	2.00
Pump man and helper (set up)	3.75
Mixing (2 men, 6 hr.)	5.00
Cement (10 tons)	200.00
Total	\$219.25

[1] *Trans. Am. Inst. Min. Eng.*, **48** (1914), 651.

[2] *Bull.* **69**, *California State Mining Bureau*, **1914**, 154.

HANDLING OIL

In pumping wells, or in the case of wells flowing at a moderate rate, the oil can be pumped to storage without appreciable loss if the proper precautions are taken.[1] All pipe lines of the gathering system should be laid in trenches and buried sufficiently deep for protection from heat or cold. Each well is generally gauged separately for its production, and consequently tanks are installed at each well and the oil is measured there before being pumped to storage. These tanks may be from 25 to 100 bbl. in capacity, and one or more are placed at each well, depending upon the amount of production. If the well is making sand, a box with baffle boards is placed upon a scaffold,[2] so that it discharges into the tank and the lead line from the pump runs into it. By the use of tanks and sand boxes, the running of oil into earthern sumps can be avoided and a great deal of oil may be saved from loss by seepage and evaporation. Tanks should have close-fitting covers to prevent loss of the more volatile constituents.[3] The use of tail pumps is to be recommended where the oil cannot be gravitated from the well; but the tail pump can be used only upon wells making a production up to 350 bbl., and a steam pump becomes necessary on a larger production.

For a production of 1,000 bbl. per day, two 2,000-bbl. tanks are sufficient for storage; while for a production of from 5,000 to 6,000 bbl., 5,000 to 10,000-bbl. tanks are generally used. When it become necessary to store oil or where a gusher may be expected, 55,000-bbl. tanks are built; but where the oil is kept moving daily in small shipments, they are really unnecessary. Shipping tanks should be equipped with three or more sampling cocks, placed at proper intervals on the side, and the suction line to the pump should be 16 in. or more from bottom, to prevent the sludge

[1] On oil storage, see BARRINGER, *Petrol. Rev.*, Jan. 22, 1916.

[2] The sand can be shoveled out of the box, to prevent it from entering the tank.

[3] Certain operators use a water-covered storage tank with the sides protected by a wooden cover to prevent evaporation in light oils, while others paint the outside of the tanks white to reduce the intensity of the sun's rays (see p. 716). The large shipping tanks in any case should be well protected and the oil discharged from the gathering system into the tank through an overhead discharge which should run within a few feet of the bottom.

and water from being delivered to the purchaser. A swing-pipe is generally used on the inside end of the suction, so that oil can be drawn from any level. The volume of the heater coil and all dead wood is subtracted from the tank at the time that it is measured or "strapped."[1]

According to California practice, upon obtaining a full tank of oil, the gauger of the purchasing company "thiefs" or samples it at three or four levels, the samples being placed in different receptacles. The "thief" is a specially constructed bucket which can be lowered to a certain point and a sample of oil taken from that particular level. Samples are usually obtained at the bottom of the discharge, at the top of the oil, and two intermediate samples at equal distances. These are taken to the test house, where, after shaking, 50 c.c. of oil from each are poured into a 100-c.c. burette and 50 c.c. of gasoline are added. After being thoroughly mixed by shaking, the burettes are placed in a "centrifuge" capable of making 1,000 to 3,000 revolutions per minute and revolved for 20 min. The centrifugal motion throws the sediment and water to the outside or bottom point of the burette; the readings are taken and multiplied by two, there being 50 c.c. of oil to 100 c.c. of fluid. The limit of water and sediment is usually 3 per cent. and anything in excess of that figure is rejected. The temperature and gravity are taken by pouring parts of each of the samples into a hydrometer jar and making a reading. In heavy oils, some purchasers use one-third each of carbon disulphide, which "cuts" the asphaltene oil and gasoline.

The use of concrete reservoirs for oil storage is said to be not always satisfactory, since it is difficult to construct a large reservoir through which the oil does not seep to some extent.[2] It is frequently necessary to run water into concrete reservoirs to save the oil, the seepage sometimes amounting to hundreds of barrels per day. Oil should be shipped as soon as possible after being produced, as the evaporation, especially in warm weather, is excessive. Oil standing in open earthen reservoirs has been known to shrink as much as 40 per cent. in the course of from 15 to 20 days. Oil, between 33° and 34°Bé. gravity, standing in tanks and exposed to the open air for 24 hr., has been known to lose 4 per cent. of its original volume by evaporation.

[1] See p. 705.

[2] On concrete reservoir construction, see p. 697.

CHAPTER VII

THE VALUATION OF OIL PROPERTIES

By Roswell H. Johnson.[1]

An oil property may be said to have two values, or to have value in two different senses. First, there is the *exchange value*, that amount for which it can be sold; and second, its *productive value*, or the amount of present capital which the income can repay with that rate of interest necessary to attract capital to such ventures, including the consideration for risk. These two values are seldom the same, and the skilful appraiser endeavors to ascertain each value, so that if the exchange value is the higher he can recommend the sale of the property; if the lower, its purchase.

In determining a selling price, the appraiser should ascertain the productive value as his basis, because he should not sell *below* this. The mere broker is tempted to feel satisfied if he knows only exchange values; but if he does not understand productive values, he may sell too low and he may not foresee fluctuations in exchange value caused solely by a change in productive values.

The productive value of an oil property is, of course, determined by the gross profit which may be expected from it. The gross profit varies directly with the size of the revenue and inversely with the size of the outlay.

OUTLAY

The outlay may be classified as follows:

1. To purchase.
2. To retain, if undeveloped.
3. To develop, if undeveloped.
4. To continue development, if obtained partly developed.
5. To put into a satisfactory condition, if purchase wholly or partly developed.

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6. To maintain.
   (A) Regular maintenance:
      (i) Wages.
      (ii) Supplies.
      (iii) Transportation of supplies.
   (B) Occasional outlay:
      (i) Pulling and replacing cups.
      (ii) Cleaning.
      (iii) Miscellaneous.
   (C) Accidental outlay:
      (i) Wind.
      (ii) Lightning.
      (iii) Fire.
7. Taxes.
8. Share of general expenses.

These factors are treated in turn.

1. To Purchase.—The purchase consideration may be fixed or contingent. If fixed, it is sometimes, although rarely, wholly in cash, but more frequently partly in cash and partly in deferred payments. A majority of sales, however, are wholly or partly contingent. This is often as bonds or stock—either preferred or common, or both. In other cases it is expressed as "payment out of the first oil." This is, of course, contingent, since there may be no first oil, or an insufficient amount.

2. To Retain.—A very large proportion of all developed properties were not drilled until after such a delay after leasing as to demand one or more payments of rental. This may happen because the operator takes up a large block of leases and drills a test-well on one lease. If successful there, he ordinarily drills successive wells outward, a location at a time. By the time the first well is drilled on some of the outlying leases, there frequently has been such a delay that one or more rental payments are necessary.

Many leases are taken scattered throughout a large area, thought in general to have possibilities, in the hope that successful development near some of these will make them sufficiently promising for a well, or to appreciate the value of the lease so that it can be assigned at a profit. While it is not a sound method, it has been practised a great deal. The result is to make a very heavy load of rental payments. Some of the leases are often dropped after a few such payments, if, in the meantime, the region has been inactive or has been condemned.

A similar type of leasing is to take up leases surrounding those held by a company which is drilling a "wildcat." While this has the disadvantage of a higher bonus, it has the advantage of few or no rental payments, since, in case of failure, the leases are often promptly dropped.

Rental payments have the effect of spreading out development, as an operator, to stop these payments, will, if the sacrifice is not too great, drill the first well on another adjoining lease rather than drill another well on the same lease. He is sometimes led to take too long a chance and so drills an unnecessary dry hole, although this results more frequently from drilling at the end of his term, when further rentals will no longer suffice to hold the lease.

The Indian lease in Oklahoma is peculiar in calling for a higher and higher rental with successive years, thus putting pressure to bear to drill prematurely—a pernicious practice operating against sound conservation.

3. To Develop, if Undeveloped.—The investment necessary to develop a property must be estimated by comparison with that of the most analogous properties and the fluctuation of the unit costs. In a new region, this is difficult until after the first well has been drilled, when the principal items—price per foot to drill and the amount and size of casing and tubing required and its transportation—may be reasonably well estimated. The dip should be known, especially if the property is in such fields as those in California, the Rocky Mountain states, or in the Coalgate-Poteau gas district in Oklahoma. Otherwise the producer cannot estimate, on account of varying depths, the cost of drilling other parts of the property.

If the country is very rocky, with steep topography, or if swampy or subject to floods, allowance must be made for the heavier costs of transportation and delays. The distance from the railroads, when more than 10 miles, as in several of the Big Horn pools, is of vital importance. It has so far prevented the development of the otherwise promising San Juan field in Utah and has postponed the development of Grass Creek Basin many years.

The labor costs become unduly high in some foreign countries where oil development is not yet established and skilled workers have to be imported. Indirectly, tropical diseases may greatly raise the labor costs, as in Colombia. Another cause of increased

costs, sometimes not adequately allowed for, is remoteness from supply centers. Great expense is thereby caused by waiting for parts or supplies for repairs, or to overcome unforeseen contingencies, especially in fishing. Where there is no proper housing near the property, the expense of such construction for the men must be planned for.

The property may be wholly unsurveyed in a region without land corners, when provision must be made for extensive surveying. There is further the expense of a geological survey, frequently, but improperly, omitted, and especially important in regions of high dip.

In fact, there are so many expenditures, in addition to the usual ones, in foreign pioneering work, that it can seldom be successfully accomplished by any but large companies with ample resources.

4. To Continue Development when This is not Complete.—By development, the miner means outlining ore with workings which demonstrate the existence of and make possible the removal of the ore. In oil production the term is used when all the wells are completed and made ready for operation. Properties are sometimes sold when one well has demonstrated real value plus a further speculative value. More frequently the sale takes place when the most promising part has been drilled, but there is a further part that may be worth drilling with probably less favorable results. This poorer result arises partly because of natural inferiority and partly because by this time the diminished pressure has greatly reduced the extractability of the oil and the wells have lost some oil to surrounding wells. Some properties are believed to be as fully developed as is possible, the undeveloped part being judged unproductive. Examination by the prospective purchaser may convince him that some of this undeveloped territory is worthy of test and it may in part prove to be so.

A property is sometimes bought while still flowing. It should not be considered fully developed, and allowance should be made for the money necessary to install a "power" and to make the change. Even when a property is pumping by separate engines supplied with steam from batteries of boilers, it is so likely that a central "power" should be installed or electric pumping instituted in certain contingencies, that the development may be considered incomplete and allowance should be made in the

same way for this completion of the development. Proper plants for supplying water and gas or connection with lines which supply them must be provided in development.

5. To Put into a Satisfactory Condition.—A new management is very likely to find a lease unsatisfactorily equipped, even though it is already "on the power." For instance, the shackle lines may be badly slung by ropes where they cross ravines. There is, therefore, very frequently some excess expenditures over maintenance during the month or so after the transfer. These expenditures are development expenditures, and should be estimated and allowed for in the valuation.

6. To Maintain.—Maintenance should be divided into *regular*, *occasional* and *accidental*.

The calculation of the *regular maintenance* may be, in general, subdivided into *wages*, *supplies* and *transportation*, the rates of which may be ordinarily ascertained with little difficulty. It presents, however, a few characteristic features, depending upon the system employed.

To have the wells all completed and all still flowing on medium or large leases is uncommon, except where the sand is shallow. In the Delaware (Oklahoma) pool this condition was realized. The result is always amazingly low maintenance, because it is so nearly automatic. Wherever very low maintenance per well is reported, one may suspect that the property is flowing. Maintenance may be calculated per well-day, acre-day, or per barrel. It is especially by this last method that flowing properties show such low maintenance. Brokers have sometimes improperly made use of this low maintenance in figuring profits for a lease. However, a deal could hardly be consummated before the heavy expense of pump equipment would be necessary and maintenance be increased to the normal amount. It is important, then, to consider this low maintenance, while the wells are flowing, merely as a passing phase. The maintenance varies with the method of pumping.

(*A*). Individual steam engines and boilers: The maintenance is highest with this method of furnishing power, so much so that, except for isolated wells, it is generally later supplanted. A relatively great amount of labor is required to tend all the scattered boilers, even though they burn gas.

(*B*). Individual gas engines or electric motors: Where the central power and shackle lines are infeasible, the lowest maintenance

cost is secured by individual gas engines where gas is cheap or by electric motors in certain other contingencies—equipments which obviate many scattered boilers.

(*C*). Central power and shackle lines: The lowest permanent maintenance of any group of settled pumping wells is obtained by this means, except under certain limitations, *viz.:* (*a*) The necessity of retaining an engine at the well because of very frequent pulling or cleaning; (*b*) very great depth of wells; (*c*) great distance between wells; (*d*) great topographic difficulties, and (*e*) inability to obtain the right to lay the shackle lines, as in town lot development or very valuable land. These obstacles are more and more being overcome. When the Glenn pool was still flowing or on individual engines, some thought it was too deep for "powers," yet "powers" are now used for much deeper wells and probably will be used for still deeper ones. "Powers" not infrequently handle all the wells, where not too deep, on a square 160-acre tract. One power in northern Pennsylvania successfully handles 35 wells.

The occasional maintenance items are by no means negligible. These are least where the wells are cased to the top of the sand, or where the wells are in a hard sand which was well cleaned at first, with a liberal pocket drilled below the sand. In these circumstances only lubricating oil and the inevitable wear of cups (which would be relatively less) need be provided for. At the other extreme, we have wells that require so much cleaning and pulling to replace cups, because of the very soft running sand, that their maintenance is a serious item. In fields where such difficulties are regularly met, we find strainers of the proper mesh in use. These should also be used in a few areas in the fields which are in general hard sand fields, and more widely used in others where it is thought to be necessary to bail the oil, as in Russia. While the appraiser should ascertain how much cleaning and pulling have been necessary in the past on the property in question and also on the neighboring leases, it must be remembered how much this depends on the thoroughness of the cleaning after the shot, the presence of adequate pockets, the proper placing of the shot below the upper part of the sand, so as to avoid leaving only a shale roof to the shot hole, and the proper placing of the perforations below the working barrel. Good management in these points, to be amplified later, very materially reduces maintenance cost.

Recently additional items of maintenance have appeared, and will continue to appear, as the art of obtaining the utmost amount of oil from the sand that is feasible receives the great attention it deserves. These methods are all in their infancy, although we may well expect that in the future we are to hear of water flushing, pressure conservation, electric heating, etc. For the immediate present, however, the appraiser would better value the property without reference to the higher extraction in these ways, because, until there has been more experience, there might be extra experimental costs. This leaves these ventures, promising as they are, to be considered as separate investments. In a few years some of these devices will become so customary that they will be figured in the regular maintenance.

Accidental Maintenance.—The hazards of the oil field are likely to be underestimated. The location of the property is a factor in estimating these hazards. The wind hazard, so important where the derrick is used and left standing, is greater in Kansas, in the northern tier of counties in Oklahoma, and in southwestern Illinois, since tornadoes are most frequent there. The use of guys is far less of a protection than is supposed.

The fire hazard is greatest where the hot dry summers in untilled regions lead to prairie fires. This condition applies especially to the Osage Nation in Oklahoma. In such regions fire breaks should be ploughed around derricks and buildings. Sometimes early intentional burning may be desirable before the grass is too long or dry, but this, in itself, is, of course, dangerous and should only be attempted by experienced men. Such work, when carried out annually, as a regular practice, should be included in regular maintenance. Flood hazards are so local as not to be easily overlooked, but there are so many oil properties in river bottoms subject to flood that the situation needs to be understood. One otherwise valuable river-side property in the Cimmarron River in the North Cushing pool, was abandoned by its operator, so great were his flood expenses.

The danger from lightning is notoriously high for oil tanks and derricks. The common belief that rising gas itself attracts lightning is questionable, but the height of the isolated derrick wet by the rain, and the iron of the tank offering so large a metallic surface, are quite enough to make this a hazard worth allowing for. Unfortunately, statistics are not available.

7. Taxes.—The item of taxes upon oil and gas properties

shares the large element of variation which is characteristic of this industry. This is to be attributed to the fact that no settled method has yet reached general acceptance, and that oil offers a shining mark to legislators, because its very speculative character gives a false appearance of very great average returns. Largely for the sake of stability, an *ad valorem* tax on production is desired, as the rate is less likely to fluctuate than one levied upon the physical property; and it varies more directly with the value of the property than a tax on equipment, which would be disproportionately high on old wells yielding very small profits. The proposal to tax prospective value as well as production has a certain plausibility. Yet the speculative element is so relatively high in undeveloped lands, and the price fluctuates to such a degree owing to the periodic discovery of market breaking pools, that it hardly seems feasible.

There is, in addition, the federal tax on corporations. This should be repealed, since the small corporation with little profits carries a burden not intended for it, because it bears a name that savors of wealth to the undiscriminating. The heavy fees levied by the states for incorporating, for engaging in business in states outside that of incorporation, and for enlarging the capitalization, are essentially taxes which add an appreciable item to costs in the companies organized specifically for one lease or for a few leases.

8. Share of General Expenses.—We include under this caption those expenses not specifically chargeable to either developing or operating a property, unless it is the only one owned by the individual or company. Most properties are one of several leases, some of which are not contiguous, that must share several items of expense. These are especially those of the office, such as managing, accounting, legal expense, etc. Some of the transportation not easily divided among the properties may be charged here. This burden will be very high when the leases are all small and considerably scattered, as is so common in the Cherokee Nation, Oklahoma. The contiguity of leases is a very important element, both in maintenance as well as in the matter of general expense. One superintendent can perform the services of several where the property is compact. The large size of the properties in the Osage has been advantageous in this respect. This, with the absence of rentals there, has served in part to compensate for the heavier burden of royalty.

It is not safe to assume that the general expenses under a new management will be the same as those under the old. The number of properties that will divide the expenses will probably be different. Again, it may be possible to eliminate some unnecessary expense. On other occasions, the property may have been operating under a staff inadequate in quantity or quality, so that increased expenses will be necessary. It is very important to figure what the costs will be. What they have been is, of course, the principal guide, but by no means the only one, in deciding what they will be in the future.

INCOME

In dealing with outlay, the uncertainties have not been much greater than in other industries, and the methods of determining the costs have not been very different from what one might find in some other industries; but in considering the income of oil and gas properties, we are dealing with a unique situation that is worthy of extensive analysis. The income factors may be classified as follows:

I. Terms of the holding.

II. The amount of production and its distribution in time.

III. Agencies which may interfere with a normal production.

IV. Possible improvements in methods during the life of the lease.

I. Terms of the Holding.—In estimating the revenue one first ascertains whether the company receives all the product, or the product less a given percentage, as in royalty, or less a fixed sum, as is still quite common for gas. This has a double importance, first, because of the deduction itself, and, second, because the length of the working life of the well depends in large part upon the size of the deduction.[1] The higher the royalty, the earlier the abandonment is forced, and thus less production is obtained. Royalty might be considered an expenditure; but since the purchasing company usually, by means of a division order, transmits the lessor's share to him direct, it is better not to count it into receipts, and hence not into expenditures, and thus much accounting is saved.

In cases of leases which do not run "as long as the oil and gas

[1] R. H. Johnson, "Sliding Royalties for Oil and Gas Wells," *Bull. Am. Inst. Min. Eng.*, No. **102**, 1291–1294.

is found in paying quantities," as in minor leases or Osage leases, one must ascertain the following three elements, if there is reason to believe there will still be paying wells on the lease at the time of expiration: first, the gross profit received up to the expiration of the lease; second, the price to be received for such movable property on the lease as may be sold or that may be removed to other properties if the lease is not renewed; third, if renewal is doubtful, the chance of success in getting the renewal; if renewed, the value of the renewal. This renewal value is the productive value after renewal less the consideration enforced for the renewal. This consideration will ordinarily be less than the productive value, because the wells are likely to be old and the operator who has the lease can ordinarily obtain more from them because of his knowledge of the wells than could an outsider. There is also the threat to "pull" some of the wells that are near enough abandonment, so that the land owner would have difficulty in preventing it.

II. Amount of Production and Its Distribution in Time.—The estimate in advance of the amount of oil or gas to be produced is the crux of valuation. The amount of oil to be obtained is the result of these sets of factors: (A) Those determining the amount of oil or gas underlying the property, (B) the proportion of oil and gas in the sands that are exploited, and (C) those determining the percentage of this which can be produced.

The amount of oil or gas underlying the property depends upon the following considerations, for each of the sands; there are more, if more than one.

(1) *The Capacity per Unit Volume of the Reservoir.*—This is, by no means, the porosity, as frequently stated, for some pores are so entirely surrounded by grains or cement that their contents could not escape. Furthermore, a high degree of porosity is of no avail if the pores are so small that adhesion or "capillary drag" prevents the fluid contents, at the given pressure, from escaping at a sufficiently rapid rate to make a paying well. Determinations of mere porosity, then, are relatively valueless. The determination of value to the oil producer is that of the amount of fluid that can be taken out of a given rock—its yield. No satisfactory laboratory method has yet been devised by which the yield of a small piece of sandstone can be determined. The nearest approximations are as follows:

(*a*) Its *oil content*, which is determined by grinding (if conso-

lidated) and extracting by solvents. The difficulties are: (*i*) this includes some oil that cannot leave the pores naturally; (*ii*) the sample is at atmospheric pressure and will give a different oil content from that which it had *in situ* at the actual pressure, particularly owing to the formation of gas bubbles from what was dissolved gas when the pressure was relieved; and (*iii*) in case the sand is unconsolidated, its content changes as the interrelationship of the grains is disturbed in being removed.

(*b*) Its *reception capacity*, which is best measured by an adaptation of Buckley's method of determining specific gravity, porosity and absorption of building stones.[1] The sample of rock is rid of any possible oil content by "petroleum ether" treatment, this solvent being forced in and out by change of pressure. After being thoroughly dried at 110°C. and no higher, so that no chemical changes are produced, it is again treated with petroleum ether and again dried. After weighing, it is placed in a bottle and a standard oil free from gasoline, such as claroline, is introduced at the bottom as the air content is exhausted from the rock by a reduction of the pressure in the bottle. The samples remain in the bottle at $\frac{1}{12}$ atmosphere for 36 hr., after which the pressure is slowly raised to that of the room. The amount of oil imbibed can now be determined by weighing at a standard temperature, after removing the surplus oil with bibulous paper. Cold oil is used instead of hot water, as in Buckley's determination, not only because it is more analogous to the crude, but also to eliminate evaporation during weighing and avoid dissolving any of the sandstone, in which the cement especially may consist partly of soluble minerals.

Capacity, thus determined, is not the yield, because capillary drag and adhesion render the yield much smaller. "Reception capacity" and yield would, however, be highly enough correlated to make "reception capacity" the most valuable laboratory determination.

Any method based on samples has two great inherent difficulties: first, to get a representative sample, since a piece blown from a well has an uncertain origin and shows nothing as to the variation; second, to know what allowance to make for the difference between the laboratory conditions and those in the reservoir. Laboratory determination from samples is therefore

[1] *Wisconsin Geol. and Nat. Hist. Survey, Bull.* No. 4, Econ. Series No. 2, pp. 63–69.

unsuitable, except in the very unusual conditions where the next method is unavailable.

(c) The *comparative production* figures from adjoining leases are used; or lacking these, available data from leases that seem to be the most similar in the most essential features to that of the property in question. Eventually, we may hope that a great deal of such data will be available to all. For California we have the excellent data expressed in a useful way in McLaughlin's "Petroleum Industry in California,"[1] and in Lombardi's "Valuation of Oil Lands and Properties."[2] May we not look to the Federal Bureau of Mines to publish decline curves of individual wells and properties in all important pools in all the sands of the country? In the meantime, reliance must be had on what data of this sort can be preserved and exchanged by individuals.

The greatest aid in such comparisons is the construction of decline curves and the calculation of decline rates. The attention of the oil producer to these graphic methods, which are very clearly presented in Brinton's "Graphic Methods of Presenting Facts," would be amply rewarded, not only in this connection but in many others in the field of oil and gas production.

(2) *The Size of the Oil or Gas Deposit Tributary to the Well Studied.*—This depends upon:

(a) Thickness of the reservoir.

(b) The part thereof occupied by oil rather than water or gas; or, in gas properties, that part occupied by gas rather than by fluid.

(c) The distance of the neighboring wells or of the boundaries of the reservoir.

(3) *The Extractability of the Oil in the Sand.*—This may be neglected in the case of gas, for, by the use of vacuum pumps, the extractability of gas is very high. Moreover, gas is extractable from sand of lower porosity than is oil. Since ordinarily the contact between adequately yielding sand and inadequately yielding shale is a transitional one, it follows that a given reservoir is smaller as an oil than as a gas reservoir. An additional amount of gas is given up from solution in oil if there is oil in the same reservoir, as the pressure goes down. If there are wells in another part of the reservoir, where the upper part contains

[1] *Bulletin* 69, *California State Mining Bureau.*

[2] *Western Eng.*, 6, 153.

gas and the lower or middle part oil, of course a great deal of gas is lost to the property being valued, but the amount varies according as the other operators are provided with separators or use their casing-head gas, and at what pressures.

The extractability of oil depends upon:

(*a*) The initial pressure of the reservoir.

(*b*) The presence of a considerable amount of gas in the same reservoir, either in solution or free.

(*c*) The rapidity with which the oil, and more especially the gas, is being exhausted by the completion of other wells in the same reservoir.

(*d*) The dip of the reservoir.

(*e*) The viscosity of the oil at the reservoir temperature.

(*f*) The encroachment of water.

(*g*) The nature of the sand.

(*a*) *The Initial Pressure.*—The general belief that deep sands "hold up better" than shallow sands is one result of the important rôle played by pressure, since pressure ordinarily increases with depth. The natural impression that oil flows into the hole merely as a result of gravitation is difficult to overcome. Yet as the passageways in a series of sands become increasingly small, adhesion and capillary drag becomes so great that the oil no longer flows into the well at a paying rate when the pressure reaches a certain degree. In most of the consolidated sands of the Appalachian, Lima-Indiana, Illinois and Mid-Continent fields, the pressure factor is quite the predominant one as compared with gravity. If a piece of oil-filled ordinary sandstone is laid upon a plate, it is surprising how little of its oil will run out. The production of a well declines step by step with the reduction of pressure; and where the sandstone is consolidated and not very porous, the well ceases to have a commercial production before the pressure has been reduced to that of the air in the hole. A high pressure then leads one to expect a much larger and longer production.

(*b*) *The Presence of Gas.*—Since liquids are so slightly compressible, the expulsion is mainly dependent upon the expansion of the gas-filled portion of the reservoir from its own natural expansion and the yielding up of dissolved gas from the oil as the pressure declines. Moreover, this gas is not all contributed to the gas-filled portion of the sand, but comes to exist as gas bubble nuclei in the several larger pores. It is by virtue of this

that the oil is able to leave the relatively fine-grained reservoirs; otherwise it would be impossible. In illustration, a cube of sandstone filled with carbonated water yields more water than one filled with pure water.

(c) *Relation to Other Wells.*—A quick decline of the pressure would greatly reduce its effectiveness for expulsion. The close proximity of many other wells therefore reduces the value of a well, in addition to the effect in reducing the contributing area. For this reason, a large lease, or a lease alongside a property not drilled because of litigation or other difficulties, is worth more per acre than a small one or a lease adjoining property being worked. Properties in a region where line wells are by custom drilled farther back are thus more valuable. The productive value of very small leases is so much greater if combined with those of a neighboring lease owner, that an effort should always be made to reach an equitable basis for sale, purchase or trading, in order that the superfluous wells may be eliminated. In spite of the obviousness of this situation, the ridiculous sight of town-lot crowding is seen nearly always when production is found where the land ownership is thus parceled, although experience has so often demonstrated that such operations are losses in an overwhelming percentage of cases. The last instance, that of Evans City, Pa., in 1915, was as bad as usual. Irregularity of outline makes the protection of a lease so expensive that it will pay much better to sacrifice some of it to a neighbor's offsetting well.[1] The author once recommended the sale of a nearly cross-shaped lease, owing to this consideration, and the price received was a good one, since the defect failed to impress the undiscriminating purchasers.

(d) *Dip of the Reservoir.*—Properties high up the dip, where the dip is considerable, say 100 ft. to the mile or more, and where the porosity of the sand is high, suffer in value by reason of the loss of their oil to the lower leases, as the oil is withdrawn from the latter. By the same reasoning, the value of the lower properties is enhanced by the replacement of the oil withdrawn by that from above. This principle must not be pushed too far, for, in sands of "low porosity," gravitation plays a very small rôle.

[1] A method for determining more precisely the advisability of offsetting well for well will be found in JOHNSON and HUNTLEY'S "Principles of Oil and Gas Production."

(*e*) *The Viscosity of the Oil.*—The higher viscosity of very heavy oils reduces their "extractability." But the difference is lessened, owing to the fact that for about every 60 ft. in depth there is an average rise in temperature of about 1°F. (this is quite variable). In high pressure consolidated sands Quick[1] believes there is a refrigeration, caused by the sudden reduction of pressure at the sand face, a condition which may in some degree counteract this higher temperature. He contends that such refrigeration in the case of high paraffin oils seriously reduces the flow by clogging the sand face.

(*f*) *The Encroachment of Water.*—When a pool has encroaching water, all properties down the dip have their value reduced, because of the liability to a shorter life from this cause. Those high on the dip have their value enhanced, because new oil is brought up as they exhaust the original charge. Unfortunately, it is difficult to foresee encroachment, so that allowance for it is in general restricted to the period after it has made itself felt in the lower part of the pool.

(*g*) *The Nature of the Sand.*—The texture of the sand is of supreme importance. A very fine sand or a shaly sand might have the same volume of voids and the same oil content, but would necessarily have a very low extractability. If the sand texture is very uneven, small volumes of very porous sand being distributed in a finer matrix, the extractability is reduced, for only communicating systems reaching the hole are available.

A very common error in determining sand texture is to judge of it by the grains of sand after these are broken apart. A more important feature than the size of the grains is the amount of cement between the grains. The uniformity of the sand grains is more important than their size above a certain critical diameter. Roundedness, the high percentage of quartz grains, and the size of grains, are all more important, not directly but because these qualities are correlated in some degree with a lesser amount of cement than on their own account.

III. Agencies which may Interfere with a Normal Production.—The career of many oil properties is a checkered one, quite aside from the accidental features mentioned earlier. While it is true that, in general, marketing is quite serene for the producer, since his sales are so nearly automatic, nevertheless there are certain disturbances. Pipe lines are broken at times, more

[1] MILES W. QUICK, *Nat. Petrol. News*, **5**, 1–4.

especially by floods, which may shut down production for several days. In the winter time, the greater viscosity of many oils reduces the runs. On other leases some of this oil is "cut" (emulsified), so that it must be treated at some expense or loss, or in some cases burned; but fortunately this condition usually passes as pressure naturally declines.

Most important, however, are the "gluts" to which the petroleum industry is especially liable, owing to the suddenness with which new promising pools are developed. The pipe-line companies ordinarily do not lay a line to a pool at a distance from its established lines until the pool has demonstrated its importance. Not only do the runs from the new pool suffer, but also those from many other properties contributory to the same lines, since the runs are cut down to a given fraction of the whole production. This very seriously disturbs the incomes of the properties. While much of the oil production is simply postponed for later pumping, some oil becomes "inextractable," owing to the greater pressure loss in proportion to the oil raised. Caution is necessary in accepting Oklahoma and California decline curves without correction, lest they include such a decline curve artificially flattered.

IV. Possible Improvements in Methods During Life of the Lease.—In this day of enhanced interest in methods of higher extraction,[1] we may expect from among the numerous suggestions of pressure conservation, water-flushing, Marietta plan of utilizing compressed air, electric heating, over-deepening,[2] etc., some decided improvements of efficiency within the next few years.

The Price of Oil and Gas during the Life of the Lease.—There is a great range in price for the different qualities of oil. If the lease produces an oil much better than the general field, as at Cushing, inquiry should be made as to the possibility of shipping by tank car to some refinery competing with the regular purchaser of the oil. If the property is large enough, consideration should be given to the erection of a refinery by the operators of the lease to obtain the benefit of the better quality.

If the oil is ranked lower than the general grade, a similar procedure is indicated. The Wann, Oklahoma, oil was bought as an inferior grade at a lower price until a company for the

[1] See L. G. Huntley, p. 374, this volume.

[2] R. H. Johnson, United States Patent 1083018.

manufacture of roofing paper and asphalt was established and built a pipe line to it.

Few minerals suffer the violent fluctuations in price that crude oil does. Oklahoma crude rose from $0.35 to $1.05 in 3 7/12 years, and then declined to $0.40 in one year because of the Cushing pool. Even Pennsylvania oil, far removed as it is, was forced, solely by the overproduction at Cushing, during the same year down from $2.50 to $1.35. With such fluctuations in income, which affect expenditures relatively slightly, the valuations of properties necessarily fluctuate violently. The efficient appraiser must therefore understand the various elements which affect the future course of the price. He should, if for no other reason, therefore, be familiar with the geology of the various fields, and the nature and stage of development of the more important pools. A great amount of significant information is readily carried for the appraiser's use by keeping graphs from month to month.[1] These graphs should include the number of new wells, the amount of new production, the amount of total production, the average size of new wells, the percentage of dry holes, and the stocks and prices for each of the several great fields. In addition, the appraiser will watch for the significant, determining, dry holes or poor wells around the large developing pools. Probably the greatest fault of the inexperienced is to overestimate the bearish effect of every new pool. Witness the Paden and Holdenville strikes in Oklahoma in 1915. Consumption is increasing so rapidly that many new pools are required to satisfy the demand and only a very small percentage of the new pools are of market-breaking size.

The stage of progress in the methods of the petroleum industry is a factor of importance. There is a rapid extension at present of geological work in prospecting, so that the rise in price which has just now set in with the decline of the Cushing pool, will probably be arrested by the increased efficiency of the drilling campaign that is now starting. On the other hand, after a while the number of successes will be fewer and fewer as promising areas are exploited. The condition will force another series of advances in price. While, in general, the efficiency of the appraiser

[1] J. H. G. Wolff, "California Petroleum and the European War," *Western Eng.*, **6**, 166–168, gives an interesting example. See also "Report of the Joint Committee on Graphic Methods," *Bull. Am. Inst. Min. Eng.*, No. **106**, pp. ix–xii.

depends upon his knowledge of the conditions in his own field, to foresee price changes he must have the widest and most profound knowledge of many oil fields.

THE METHOD OF VALUATION

After the appraiser has shown the varying elements in the income and in the outlay, he still has to calculate the surplus of income. But unfortunately, wells being so soon exhausted, he has the two complications to consider of the realizable value from junk (as the casing, machinery, etc., is called) and amortization. The junk differs very much in its value, depending upon whether it must be sold to dealers, or sold at better terms to a neighboring lease, or used on another property belonging to the same owners, with or without an intervening variable expense for transportation, storage and the depreciation incidental thereto. This gives an advantage to the large company.

For a good discussion of amortization in an allied industry, the reader is referred to Hoover's "Principles of Mining." Hoover thus speaks of amortization: "A portion of the annual earnings must be set aside in such a manner that when the mine is exhausted the original investment will have been restored," yet he later admits that "in the practical conduct of mines and mining companies, sinking funds for amortization are never established." The principal differences between the amortization of an oil property and that of a mine are as follows:

1. The income of the oil property regularly declines, while that of a mine does not necessarily do so.
2. Owing to this, a successful oil property yields ordinarily in three years or so its cost, and thereafter pays a slowly diminishing profit.
3. The average oil company owns several oil properties, and develops and buys new ones as the old ones are exhausted.
4. The average oil company carries for a period many leases, representing a considerable outlay in bonus, rentals, etc., which are dropped without drilling. To this, in many cases, is added the cost of a dry hole, or a contribution to a joint test that is unsuccessful, before the lease is dropped. The successful properties have a heavy burden of unsuccessful ones to carry.

For the four reasons given, many oil companies are inclined to accomplish amortization in a different way which seems well adapted to the oil business. All the income from each property

is devoted to paying the "debt of the property to the company" until it is "on velvet," when that property is for the first time considered a profit yielder. This method is illustrated by the following account form of the Sagamore Oil & Gas Company, of Bartlesville, Okla., when under the management of W. H. Johnson. This was kept separately for each producing lease of the company. The main advantages of this method are that the situation is more easily grasped by the manager and directors, inefficiently managed properties are more easily detected, and, most important, the data is in convenient form for the valuation of the property, so that the relation of the exchange value to productive value is more evident. In this way the desirability of selling a property or of buying adjoining properties is easily indicated.

Sagamore Oil & Gas Company

Production for month Barrels of oil	Price of oil for month	Income from production	Income to date	Outlay in excess of income to date	Income in excess of outlay to date	Net daily average production for month Barrels of oil	Maintenance cost per barrel for month	Remarks

A short cut in appraising is very common in the oil fields, viz., the barrel-day, an amount for each barrel per day produced by a property. This method is very dangerous and can only be depended upon for inside properties in large pools where the several properties are very similar and of about the same age. An appraisement for one property, worked out laboriously, might then be utilized for another property by this method. One reason why the method is essentially unsound is that the decline curve is not a straight line, but one where the rate of decline itself gradually declines. Again, the maintenance is assumed by this method to be a constant per barrel, whereas it gradually increases. The method assumes that the loss in valuation is just equal to the profits, which is not true. The barrel-day method implies that the age of the property is a negligible factor. However, if we plot the true valuation for each year by barrels per day, it gives us a curve ascending during the early life of the well, because the decline rate is less each successive year. After about the fourth year, in some properties in Oklahoma,

the barrel-day value, gradually declined, because the growing maintenance per barrel became so important a factor. One may say that in buying or selling properties where the other party uses the barrel-day figures, it is best to buy an ordinary Oklahoma property in the third to fifth year; and best to sell when the property is either young or old, but not to sell in that very late period when they are worth more as junk than as producers on a barrel-day basis. This time curve of valuation by the barrel-day ought to be worked out, for a typical property at least, in the field where the appraiser works.

While one should not base his ideas of productive value on the current quotation of production in terms of barrel-days, he should learn all the sales possible in these terms, so he can study exchange values, and thus take advantage of discrepancies between them and productive values.

There are two common errors as to the time of "settling." It is more variable and is later than generally supposed. The settling of a discovery well depends principally upon the time taken to drill the adjoining locations. Settling is that stage in the history of a well when there is the greatest change in the transition of the rapid rate of decline to the slow rate. In wells drilled where the data is kept by weeks or months the author has found settling in several cases between 12 and 24 months. Since settling is later than is commonly supposed, a favorable time to sell is at the end of six months, while the well is really not yet settled, although it is believed to be so by many producers. On the other hand, when purchasing properties, where quotations are made on a barrel-day basis, it is much safer to buy a well after it has produced for two years.

It is very important to appraise developed and undeveloped portions of a property separately and then add the appraisements. All too commonly the undeveloped territory is used as a vague bonus to smooth over uncertainties in the valuation of the developed portion. The appraisement of undeveloped territory rests on (1) what this territory will be worth if it is normally productive under the given conditions; (2) what are the chances expressed in percentage that this property will be productive; and (3) since there is a considerable risk, what insurance for risk shall be figured in. Factor (1) is similar to work upon developed property, while (2) is primarily a problem

for the geologist, although he will be greatly aided by the graphic device by which the proximity value is calculated.[1]

The risk element is extremely important. A very large company undergoing many risks should consider this element as nearly negligible; whereas the individual operator of small capital ought to put it quite high. It would be much better for him, unless he has unusual ability or information, to put his money with others in a large company or into an "Oliver plan" company,[2] *i.e.*, a government promoted company to operate on some favorable structure on the public lands.

The appraiser must consider the use to which his valuation will be put. If he is to appraise for taxation, the exchange value should be approximated as closely as possible. If it is for the purpose of inventory or as a basis for a merger, its productive value will be approximated. But when for the purpose of buying or selling, he must be concerned with both exchange and productive values. He will give greater relative weight to exchange value if he represents a company that deals in properties.

If one is fixing a price at which to sell, he uses the higher of these two values. If one is fixing a price at which to buy, he must also ascertain the productive value and exchange value, and place the price at the lower of these two values.

But a better policy is for the appraiser to know at all times whether exchange values are running higher or lower than productive values on the several types of properties, and then become a buyer or seller of that type, the exchange value of which deviates from the productive value.

Productive value obviously varies with the degree of efficiency of the future management of the property. Insofar as this can be foreseen, it will be used by the appraiser. The productive value is not a fixed attribute of a property, but in the nature of a prophecy. It follows then that the buyer for a company that is in a position to get a greater profit from a property, would properly place a higher valuation upon it. This brings us again to a consideration of the relative efficiency of small and large producing companies, and of companies engaged solely in production and those that integrate the several steps in the industry.[3]

[1] R. H. Johnson, "Petroleum and Natural Gas Resources of Canada," 1, 325–326.

[2] *Hearing on H. R.* 16,136, *Com. on Public Lands, U. S. Senate*, 63d. *Congress, 3d Session.*

[3] See p. 433.

There remain the obvious differences between the company that has a property already adjoining that in question, with one having a property in the same pool, and with one having none in the region. This difference is so very important that it should be the policy not to take anything less than, say, 80 acres under ordinary circumstances in the Eastern or Mid-Continent field.

In Lombardi's method[1] the cost of drilling the undrilled portion of the lease is distributed through the years at a rate so regulated as to produce a uniform profit. It is so rare that such a procedure is possible and desirable that it is best in general to charge the costs of drilling directly to investment rather than to expense, especially as most companies have several leases, for each of which a separate valuation is desirable.

It is not at all important that the income from each lease should be kept uniform. An oil company does well to try to keep its income steady merely through the ownership of many properties in various stages of development. Each property should be managed mainly with reference to its own maximum efficiency. Some leases in pools where the pressure is rapidly declining should be rushed to completion. In other cases where the pool is entirely within the company's lines the development should be planned as a careful "feeling out," so as to drill a minimum number of dry holes. In this last case, if there is overproduction, the whole property should be held back, even though dividends suffer for the time.

On the other hand, if we appraise a large company made up of many leases, we may properly make deductions from a sum of the values of the properties because of economies already indicated.

There are some large companies which, for their highest efficiency, demand a regular production, because of a selling contract or because allied with a refinery. This regular production is in contrast to the shrinking production of a single lease. In valuing such a group or properties we have an additional factor —the cost of maintaining this production at the given level. Lombardi has ably discussed this problem with reference to California.

The matter is quite difficult because it involves the continual purchase or "carrying" of undeveloped land with all its uncertainties. So far as the cost of the drilling campaign is con-

[1] *Western Eng.*, 6, 153.

cerned, there are three different approaches which should be used as checks against each other, as follows:

1. Experience of other companies. If the most analogous company keeps three "strings" at work, and they fail to prevent a decline in production by an ascertained amount, the number that would be necessary for a given production can be calculated.

2. The total number of wells drilled in the whole pool compared with the increase they produce, or the decrease that results in spite of these new completions.

3. Calculation from theoretical decline curves of the number of new wells necessary, counting in an estimated percentage of failures.

In conclusion, the appraiser should beware of his principal danger, that of underestimating the differences between properties in different sands, pools and regions. The constant keeping and elaboration of data on properties in a great variety of conditions can alone keep him from too far-fetched comparisons.

CHAPTER VIII

SOME COMMERCIAL FACTORS INVOLVED IN THE APPRAISEMENT OF PETROLEUM PROPERTIES

By J. P. Cappeau[1]

Owing to the differences in petroleums, in sand stratas, and in the location of oil properties and markets, it is indeed difficult, if not impracticable, to lay down any definite rules for the determination of the value of an oil-producing area: each property, locality or field must invariably receive separate consideration. There are, however, certain commercial factors which are always involved in the appraisal of petroleum properties; these are as follows: (1) The character of the petroleum; (2) the producing formations; and (3) the age of the wells and the physical condition of the properties. These considerations may be applied as a general basis of procedure, and, upon analysis, may be altered to meet local conditions.

THE CHARACTER OF THE PETROLEUM

Consideration is given to the nature of the petroleum, whether of paraffin- or asphalt-base, and its gravity and relative refining value; the present and possible future prices, and the markets therefor, whether established or to be created; and the question of marketing the oil, that is, transportation and selling facilities.

Nature of the Petroleum.—At the present time paraffin-base oils of light gravity are regarded as the most valuable; these yield the largest percentage of marketable products and the most valuable manufactured specialties; moreover, their markets have been long established, are of world-wide extent, and are constantly growing.

Within recent years, however, asphalt-base oils of heavy gravity have received more favorable attention, owing to the development of improved methods of treatment, which have

[1] Specialist in Oil and Gas Properties, 223 Fourth Avenue, Pittsburgh, Pa.

taken such oils out of the strictly fuel class. Then, too, the large yields of many of the individual wells producing asphalt-base oils have contributed in favor of such petroleum, since the producing cost is thus reduced.

Market Conditions.—The present and possible future price of the petroleum produced is, of course, of prime importance. As is well-known, the selling price of crude oil at the wells is governed entirely by the laws of supply and demand, an over-production occasioning a declining market, and *vice versa.* To predict the future of a business that is world-wide in extent, is without the scope of an ordinary examination of any property; but a general consideration of the whole producing área in question should determine, in a fair way, whether or not that particular country or section thereof will be subject to extreme, local price fluctuations due to the opening up of new pools of the gusher variety or whether the undrilled territory is only likely to offset the decline in the developed fields.

Where established marketing concerns are in operation, as, for instance, pipe line companies or purchasing agencies, the question of markets is of minor importance; but in a new country, where the producer must secure a market for himself, it is indeed a very serious consideration, since it requires the expenditure of a large amount of money and of considerable time.

Transportation.—In considering the marketing of a petroleum, careful attention must be given to the location of and the distance from the point of market for the product and the means of reaching this market. If a pipe line system is connected to the field or is in the locality of the property, and can therefore be connected, or if transportation by water is available, the value of the property is thereby increased. Otherwise, where such transportation must be provided by the producer, say by pipe line to a railroad, the cost thereof is usually higher than by pipe-line system and the difference is generally deducted from the price received for the product. The lack of transportation facilities, as by pipe systems with their accompanying purchasing departments, retards the development of new oil fields more than any other single factor, and has been encountered in the opening up of the California, Oklahoma and Wyoming fields, where, in each state, petroleum was known to exist in commercial quantities for a number of years prior to the time these states attained prominence as producers.

THE PRODUCING FORMATIONS

Although new producing formations are constantly being developed, in almost every oil field of any size or age there has been found one or more sand strata that stand out prominently because of the thickness of their "pay streaks"[1] and producing qualities; these strata are used for purposes of comparison, values being frequently based upon their past history and production per acre over a given period of time. In the eastern oil fields, we find, among the white sand strata, the "Second" and "Third" sands of Oil Creek, Pennsylvania; the "Brown" and "Chocolate" sands of Bradford and Elk counties, Pennsylvania; the 100-ft. "Third" and "Fourth" sands of Butler County, Pennsylvania; the "Salt Sand," "Maxon," "Big Injun," "Gordon," and "Fifth" sands in West Virginia; and the "Cow Run," "Berea," "Clinton," and "Trenton" sands in Ohio. In Illinois, the "Casey," "Robinson," "Bridgeport," "Kirkwood," and "McCloskey," are well known; and in Oklahoma, there are a number of different producing sands, the "Bartlesville" being the most productive. In the case of all of these sands, the general thickness, the thickness of the "pay streaks," and the producing qualities, are known and accordingly they are employed for comparative purposes. In the Gulf Coast, Louisiana and Texas fields, the sands occur more in irregular lenses, and the production is in "pools" and not in fields, as is the case in the more northern and eastern producing sections.

A thick body of sand in any horizon is to be desired, provided it is porous and contains one or more "pay streaks." In some sand horizons, there are several "pay streaks" of both oil and gas in the same sand body, separated by harder or non-porous strata, yet forming a continuous body, clear of breaks of shale or slates. In the McDonald pool of Pennsylvania, and in the Glenn pool, Cushing and Healdton fields of Oklahoma, "pay" or producing strata of from 30 to 100 ft. have been found, all impregnated with petroleum and gas. Such thicknesses are, however, unusual, and the average "pay" does not exceed 1 to 10 ft. of real producing sand in each well.

[1] A "pay streak" is that portion of the sand body which is sufficiently open or porous to contain oil and gas, the amount of which is determined by the action of the well while drilling through the sand.

Uniformity in the sand levels and in the character and size of the wells, is always desirable. In cases where the amount of sand, the thickness of the "pay streaks," the quantity of oil produced in a given time, and the rate of decline in daily production, can be determined on the property under examination, or on adjoining properties, a good basis may be had for estimating the probable life and value. Where a sample of the "pay streak sand" can be obtained—this can frequently be secured after a "shot"—its absorption or voids may be determined and its probable petroleum content estimated per cubic foot per acre of "pay streak" or producing sand. Data of this character may indicate contents ranging from 1,000 to 2,000 bbl. per acre-foot, of which amount it is estimated that 40 per cent. to 70 per cent. may be recovered, depending upon the character and the porosity of the sand rock. While some production has been found in shales, such occurrences are usually regarded as "freaks," and sand or sandy lime is considered the best producing stratum. The petroleum from a formation containing an excess of lime generally contains sulphur in amounts detrimental to the value of the oil; moreover, where lime predominates in the sand, the wells in such a formation have either been very porous or broken by crevices, as found in certain of the large wells in the Mexican fields.

The effect of torpedoing or "shooting" on the producing sand is of importance in the consideration of values. Some horizons respond to several "shots," while others will not respond after the first "shot." A property on which the wells are producing naturally, that is, have never been "shot," and are in a sand known to respond to "shooting," would be considered more valuable if the wells were in such condition that they could, without too much expense, still be "shot," than a property whereon the wells had already been "shot." In the first case, there would still be a likelihood of increasing the production by "shooting," which operation had already been carried out in the second instance.

The gas pressure on the oil rock is important not only from a fuel supply standpoint for operating the property, but because the rapid decline in gas pressure usually indicates a decline in production.

The amount of water, if any, in the sand horizon has an important bearing on the valuation of an oil property. The

presence of water increases the cost of pumping, and water with gas will sometimes "cut" the oil, necessitating rehandling after it is in the tank. However, some sands produce water and oil simultaneously; as instances, the 100-ft. sand in Butler County, Pennsylvania, and the "Big Injun" sand in West Virginia may be cited. Salt water is usually considered detrimental, depending upon the amount. Both fuel and water supplies are essential for the operation of a producing property, and these become a fixed charge when not obtained thereon.

Where the property under appraisal is in a new field and the sand horizon is unknown, the character of the petroleum, the nature of the sand, the gas pressure, and the production of the well, whether it holds or declines rapidly, as well as the geology of the locality, form the basis for valuation.[1]

THE AGE OF THE WELLS

The date of completion of each well, its initial natural production, the amount of "pay sand," the total thickness of the sand, the initial production after a "shot," the date and size of the "shot," the amount and size of the casing in each hole, and a general inventory of material, machinery, fittings on the lease, number of rigs, their condition, whether the wells are operated by powers or individual engines to each well, the number of wells pulled per month by reason of sand-cutting cups, or other reasons, the pay roll and sundry expense per month as to amount of oil produced, as well as taxes, both state and county, and the laws affecting oil property in the locality in which the property is situated, must all be considered. The equipment should be examined carefully in order to ascertain whether it is sufficient to handle the property, or to determine whether an additional investment will be necessary. Then, too, the value of the equipment, and the amount that could be removed and its value at junk or second-hand prices, must be estimated. The market price that can be secured for the production at the time of the valuation of the property and the probable price of the future, as well as the amount that may be produced in a given term of years,[2] are also to be estimated; and it is necessary to

[1] In this connection, see FORSTNER, *Min. Sci. Press*, **103** (1911), 578; and especially Chap. VII. On the value of geology, see HAGER, *Min. and Eng. World*, **35**, 435; **36**, 680.

[2] On the estimation of productive capacity, see MCLAUGHLIN, *Western Eng.*, July, **1914**.

ascertain approximately the time required to return the amount of investment, with interest, less the value of the equipment at the end of that time.

A fresh production, *i.e.*, one that is from one to six months old, is usually expected to "pay out" in two years, based on the price of the oil at the time. Somewhat older production may "pay out" in three years, and old settled production in five to six years, depending on the location of the fields, sand horizons, and the chances to hold or increase the production by drilling new wells, shooting or cleaning out old wells, and possibility of advance in price of crude oil. An undetermined deduction should be made to cover such possible contingencies as new fields being opened, increasing the general production and causing a decline in crude oil prices, or extraordinary expenses that may occur, such as losses by fire or wind, unexpected fishing jobs, or other accidents that may happen on a producing property.

CHAPTER IX

POSSIBLE CAUSES OF THE DECLINE OF OIL WELLS AND SUGGESTED METHODS OF PROLONGING YIELD[1]

By L. G. Huntley[2]

This chapter is devoted to a discussion of various natural phenomena encountered in the drilling and handling of oil and gas wells, and to suggestions as to the lines along which the present practice of recovery may sometimes be improved. The decline of individual wells is the direct factor in the general decline of production throughout all fields, and the efficiency of the recovery of petroleum from its underground sources can be measured by the length of time during which economic production can be sustained in individual wells or groups of wells. The approaching rise in the price of oil will lead to more attention being paid to more efficient recovery, with the object of leaving the least possible percentage of the original petroleum content in the sand when the well is finally abandoned. Some methods that by prolonging the life of wells may be helpful in obtaining the maximum amount of oil at a minimum cost, are briefly summarized on the following pages.

CAUSES OF DECLINING YIELD

The reasons for the decline of oil wells may be grouped in two classes—those due to natural causes and those due to poor management. Since the early days of the petroleum industry, improvements in methods of production have to a large extent been confined to lessening the cost of drilling wells and to reducing the cost of surface operations. Although well-known

[1] *Technical Paper* **51** (1913) of the *Bureau of Mines*, revised and considerably enlarged by Mr. Huntley, especially for this work; but published by permission of the Director of the Bureau of Mines.

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physical laws offer a possible solution for all underground problems, yet the amount of carefully gathered data is so scarce that general deductions must be cautiously made. Hence this chapter discusses both classes of the cause of decline, describes some of the remedial measures now employed, and gives suggestions as to possible means of bettering present methods of operating.

In general, the yield of a well declines in one or both of two ways: (*a*) Suddenly, after the initial spurt due to local relief of pressure; or (*b*) with relative slowness after the production has become settled.

Sudden Decline of Yield.—In most districts the wells begin with a relatively large initial production that is followed by a rather rapid decline to a stage during which the decrease is more gradual. The initial spurt, which in many cases represents the flowing period of a well's life, is due to a relief of the supersaturated condition of the sand. The sudden release of pressure results in a spurt of petroleum, usually in the form of an emulsion with spray, caused by the expansion of the contained gases, that lasts for a variable length of time. The duration of this period of high production depends on local conditions, such as the porosity and structure of the sand, the extent and development of the pool, the character of the oil, the rock pressure, the position of the well with reference to the center of production, to salt water, and to other conditions of less importance.

Carll[1] likens the producing life of an oil well in the high-grade oil fields to drawing beer from a barrel, as follows:

> The barrel is placed in the cellar and a bar pump inserted—at first the liquid flows freely through the tube without using the pump, but presently the gas weakens and the pump is called into requisition, and finally the gas pressure in the barrel becomes so weak that a venthole must be made to admit atmospheric pressure before the barrel can be completely emptied even by a pump.

This comparison is a general one and disregards all except the main factors of oil production.

Relatively Slow Decline of Yield.—The extent and rapidity of the succeeding decline is governed by several factors, which may be classified as follows:

1. Formation of waxy sediments that obstruct the passage of oil from the sand.

[1] J. F. Carll, "The Geology of the Oil Regions of Warren, Venango, Clarion, and Butler Counties," *Second Geol. Survey Pennsylvania*, **3** (1880), 262.

2. Decline of gas pressure in the district; that is, decrease of expulsive force, due to the exhaustion of the lighter and gaseous hydrocarbons.

3. Decrease in quantity of oil draining by gravity down the dip into the area affected by a well.

4. Decrease of the oil supply within the drainage area of a well on account of near-by development or the original limits of the pool.

5. Flooding by nonencroaching salt water under low pressure.

6. Flooding of the productive formation by salt water under high pressure.

7. Flooding by fresh water from the surface or from an overlying water-bearing formation.

8. Drilling of neighboring wells.

9. Poor management, such as improper casing, unwise rate and time of pumping, and failure to clean.

One of the most important of the factors enumerated is the formation of obstructive waxy sediments in the productive stratum and in the tubing of the well, owing to excessive refrigeration incident to the free expansion of large quantities of gaseous hydrocarbons associated with the crude oil in the rock. That in some fields an early decline and seeming exhaustion is premature and can be credited to this cause is evidenced by the fact that when new wells are drilled near older wells that have ceased to produce, the new ones give every indication of unimpaired pressures and vitality. It was a common occurrence in the northern Pennsylvania oil fields to find that the second and third crop of wells in old pools produced large quantities of oil after the territory had been abandoned as exhausted.

Carll speaks of the producing formation as being a "practically sealed reservoir" so far as an individual pool is concerned. As an example, he mentions the Cashup (Pa.) pool, which was discovered in 1871, three or four years after the Pithole pool—2 miles to the southwest—had been practically exhausted. When tapped, the Cashup pool showed all the conditions normal to new territory and an abundance of lively oil, which attested its energy and force in a well flowing over 1,000 bbl. per day.

The history of these pools has been duplicated in many places in Butler and Clarion counties, Pa. Further evidence that the shorter life of the more recent development in southwestern Pennsylvania and West Virginia is not due to the draining of

the oil and gas from the northern fields is the fact that the newer fields show much greater pressures and volumes of gas than the old fields ever did, even when encountered in the same producing sands.[1] To account for these changed conditions one must therefore look to causes other than any underground connection.

Another factor in the rapid decline of wells following the initial spurt is the relief from the supersaturated condition of the sand, allowing the drag caused by the capillarity and the friction of the oil through the sand to make itself apparent. The gaseous hydrocarbons in the immediate vicinity of the well dissipate themselves in the initial flow, and the production therefore falls off, owing to a lessening of the expulsive force. In flowing wells this marks the beginning of the "stripping stage." The character and porosity of the sand will influence the duration and amount of the initial flow, which, if from a loose, porous sand, will be more violent and will affect a larger radius than if from a fine compact sand.

Under ideal producing conditions the decline of a well would depend on only three main factors: (*a*) The quantity of oil available; (*b*) the rock pressure; and (*c*) the character and porosity of the sand. Hence, all efforts should aim at a proper understanding of the various conditions that complicate these main factors, govern the productivity of a well, and abnormally hasten its abandonment. The rapid decline of many wells from large producers to small pumpers, while at the same time large producers are being completed in the same vicinity, is evidence that these abnormal factors are at work.

Decline Due to the Formation of Waxy Sediment.—Petroleum in the so-called paraffin-oil fields consists of hydrocarbons of the paraffin series, which range from the heaviest oil to the lightest gas. The gaseous constituents of petroleum exist in what may be likened to a solution, much like the gas in a bottle of soda water, and as such expand and escape when the pressure is relieved by a well. The sudden expansion and volatilization of such light hydrocarbons has a refrigerating effect, like the expansion of ammonia gas in an ice machine, chilling the remainder of the liquid petroleum and causing the separation of the heaviest paraffin as an amorphous waxy sediment.

As an example of this process, a simple experiment described by

[1] J. F. Carll, *op. cit.*; I. C. White, *West Virginia Geological Survey*, 1 (1904), 171.

Miles W. Quick, of Titusville, Pa., in an unpublished manuscript, may be mentioned. A sample of light oil was cooled to a temperature of 25°F. until it was cloudy to the top. When the sample was warmed to between 60° and 70°F., the original temperature, the cloudiness did not disappear. After further heating, which caused all congelation to disappear, the sample was again cooled to 35°F., and the top half was decanted off and labeled "Sample 1." The part of the original sample remaining in the bottle was called "Sample 2." When sample 2 was warmed, its appearance was identical with that of sample 1; yet when sample 1 was cooled to a temperature of 35°F., no congelation took place, whereas at this temperature sample 2 was cloudy with amorphous paraffin.

Several interesting deductions may be made from the experiment. In the first place, although Carll states that oil and gas appear to exist in the rock, not as distinct bodies, but as one substance—gaseous hydrocarbons being incorporated with the oil as gas with water in a bottle of soda water—yet the experiment described above shows that under certain circumstances "stratification" does take place. The free escape of the light hydrocarbon gases, as allowed at most wells, gradually changes the relative composition of the oil remaining in the rock, until the accompanying refrigerative effect of the gas expansion and vaporization is sufficient to lower the temperature of the oil in the immediate vicinity of the well by overcoming convection from the surrounding rock. This results in the formation of waxy paraffin sediments, which, combining with water and fine rock sediments, clog the pores of the sand and obstruct the passage of the oil into the well.

The process accounts for the sudden failure of many wells, some situated in unexhausted territory.[1] The drop of a few degrees near a certain critical temperature has more effect on the congelation of the oil in a well than a preceding 20° change in temperature. Hence, when the petroleum becomes relatively high in heavy paraffin constituents, or, conversely, low in its percentage of light hydrocarbons, which have been exhausted

[1] As early as 1865, J. Fraser (United States Patent 49995, Sept. 19, **1865**) proposed the use of hot "carbonic oxide" for heating oil wells to remove paraffin. See also W. O. Snelling, United States Patent 1104011, July 21, **1914**; and I. L. Dunn, United States Patent 1107416, Aug. 18, **1914**.—R.F.B. and W.A.H.

in the early stages of production, the wax will soon clog the outlets and production will end abruptly. To repeat, this result is brought about both by the free escape of well gases and by the stratifying of the oil, as indicated in the experiment described above, and its effect is most pronounced near the well, where expansion takes place.

Decline Due to the Exhaustion of the Gaseous Hydrocarbons.—The decline of gas pressure in the pool through the exhaustion of the lighter hydrocarbons acts in a variety of ways to cause the decline of wells. In the first place the reduction of the specific gravity of the oil remaining in the rock indirectly affects the production, as described in the preceding paragraph. The practice of allowing the free escape of vapors instead of endeavoring to make each cubic foot of gas in expanding perform its quota of work in the expulsion of liquid petroleum, is a direct cause of the decline of flowing wells. It is almost as direct a factor in the decline of pumping wells as the intrastrata gas pressure is the means of keeping up the continuous movement of the fluid toward the well when the well is pumped.

The accompanying diagram (Fig. 135) illustrates the possibility of this loss in a typical oil well located in one of the larger pools in the United States. Attention should be called to the fact that with the entire original oil body present in the sand at the reduced pressure of 450 lb., the succeeding decline curve would differ from the normal curve shown. Further experiments and data are needed on this point, but this difference is not believed to be great. With such decreased pressure, capillarity would have an effect on the expulsion of all the oil, and, in addition, a critical point will be found to exist—differing with the conditions in each pool and well—where expulsion would be a direct function of the pressure and the frictional resistance, regardless of a relatively small difference in the percentage of oil saturation in the sand.

As another indirect effect, may be mentioned the flooding of oil pools by water, owing to the injudicious rapidity with which the gas is drained from the pool. The rapid exhaustion of the gas in a certain part of the field may remove the only influence retarding the encroachment of water, which may, by a flanking movement, cut off a large section of the producing area. Or water may exist in the lower part of the oil-sand, being held in check only by the pressure of the gas. If each cubic foot of gas

were retained to perform its work of expelling petroleum, the pressure would help to retard the water for a considerable period, or until the maximum amount of oil had been recovered. The Hogshooter pool in Oklahoma is an example of a producing gas district that has been ruined by having its gas drained too rapidly. Wells were commonly drawn upon to their utmost capacity; hence, as no pressure restrained the water under high pressure in the lower part of the productive formation, it flooded one well after another. Although Oklahoma has a law requiring

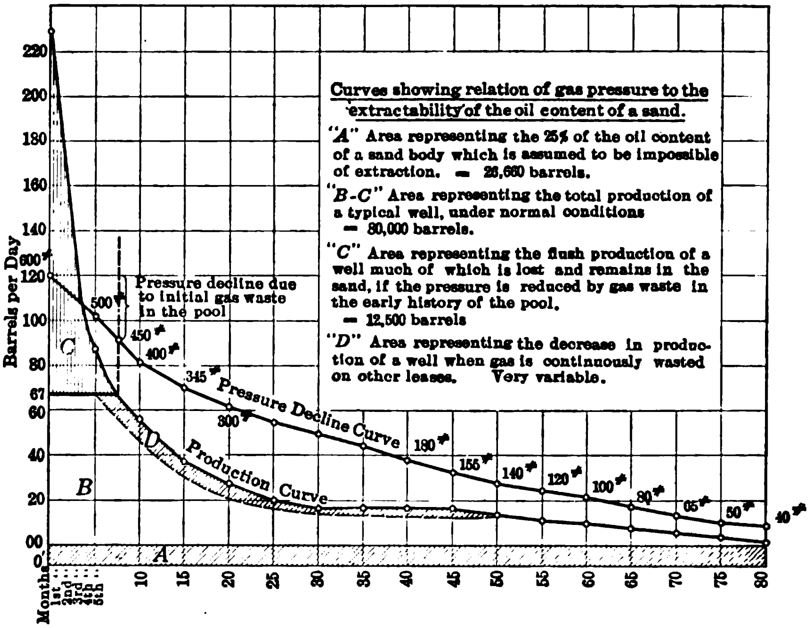


FIG. 135.—The production of a typical oil well.

that 50 per cent. of the open-flow capacity must be retained in the well, little attempt was made to comply with this law. In some pools, such as the Hogshooter, it is believed that not over 15 per cent. of a gas well's capacity should be turned into the pipe line at any time, the remainder being retained in the well to keep back the water.

DECREASE IN THE QUANTITY OF OIL DRAINING BY GRAVITATION INTO THE AREA INFLUENCED BY A WELL

The effect of gravitation in many pools is usually overlooked. That gravitation tends to cause the accumulation of the remnant

of oil in some pools is undoubted; and some instances of abandoned fields that have been rejuvenated and are again productive can no doubt be explained on this basis. In a fine-grained sand, movement by gravity may be so slow as to make it of no consequence during the operation of an oil operator's lease. However, in a soft or very porous stratum of rather pronounced dip, or one that lies in such a manner as to form a decided catchment area for oil, the movement down the dip may in a comparatively short time replenish the oil drained off by wells. This factor

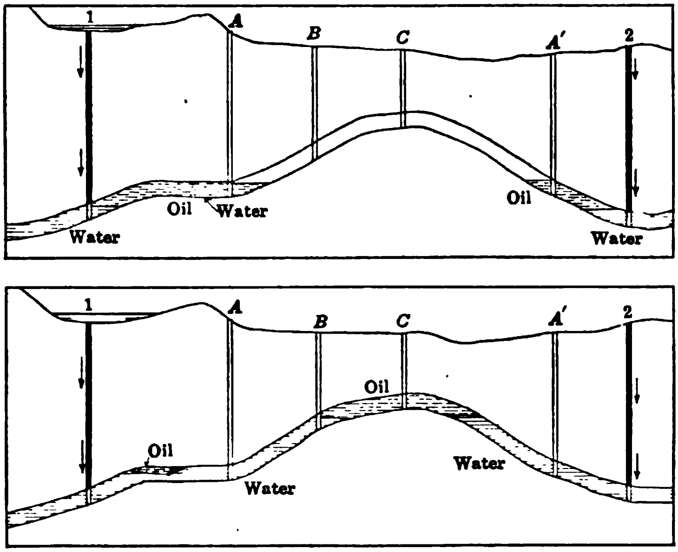


FIG. 136.—Effects of flood water and arrangement of wells drilled to utilize flood-water pressure.

should therefore be recognized. In fact, in some pools it may explain the total production of many small wells.

A coarse vesicular oil rock would be particularly favorable for this movement. In the Oil Springs pool in Ontario, advantage is taken of the annual advance of oil ahead of the fresh water influx from the spring freshets. As indicated in Fig. 136, the water in this locality obtains entrance to the oil rock through abandoned wells (as 1 and 2 of the figure), drilled from low points on the surface. Certain "live" wells located at strategic points are pumped successively, resulting in a large recovery. The possibilities of such procedure are readily apparent.

Of especial interest are the possibilities of introducing water into wells located at the crest of the dip to aid in the gravitation of the oil, assuming that the oil is already concentrated in large enough quantities to make drilling pay. This movement down the dip to a catchment area would probably be accelerated by drilling wells at high points on the dip, to admit atmospheric pressure behind the oil. This would appear a necessity, as under the assumption that the oil rock is an air and fluid tight reservoir, a medium for replacing the oil would have to be furnished from an outside source. This theory disregards the factor of gas pressure, which in fields producing heavy asphaltic oils is negligible, and in many cases is entirely dissipated in the early history of some high-grade oil fields.

In fine-grained sandstone, such as the Clinton sand in central Ohio, capillarity may so retard the action of gravity that the latter may be neglected by the operator, especially in a region of low monoclinal dips such as exist in that part of Ohio. In certain of the older Pennsylvania and West Virginia fields, however, this force may be the explanation for the "coming back" of old districts, a phenomenon that caused pioneers in the oil industry to believe that oil was being formed continually in underground sources and that its exhaustion was impossible. In fact, speculation as to the possible "coming back" of many pools has led to the spending of thousands of dollars in comparatively recent years, when carefully collected information might have shown such expenditure to be useless. Again, assuming with Carll that the oil rock is a "practically sealed reservoir," a modification of the theory of the action of gravitation in the recovery of oil may be necessary to account for wells that produce little or nothing until later wells are drilled higher up the dip, when the first wells show a marked improvement in production. The movement of the oil down the dip is then seemingly aided by atmospheric pressure from above. This theory also assumes an absence of original rock pressure or its previous exhaustion. An atmospheric pressure of 15 lb. per square inch in the wells first drilled is sufficient to keep back the oil until an equalizing pressure from behind is applied. If gas exists in the rock, its expansion will furnish this replacing medium.

The production of some wells improves after the drilling of neighboring wells, a result that may probably be explained on a basis similar to the above. In oil wells the atmospheric

pressure, combined with the retarding capillarity of the sand, may be sufficient to prevent recovery. However, the contrary effect was observed in two wells in the pool at Vinton, La. The oil is of a heavy asphaltic base with no gas. The first well encountered a "pay" sand so soft that the rotary bit dropped through of its own weight. It began to produce oil and continued until a second well was drilled close by. This second well struck the same sand in the same condition, but it immediately collapsed or "packed" and thereafter neither well produced a gallon of oil. As the rest of the field was pumping oil from this sand, and as the oil in the sand was therefore under less than atmospheric pressure, the admission of air to the sand in the second well, combined with the draft in the direction of the pumping wells in older parts of the pool, may have been sufficient to drive the oil in that direction, the sand then collapsing, possibly from atmospheric pressure, as the drillers state that the well was not flooded.

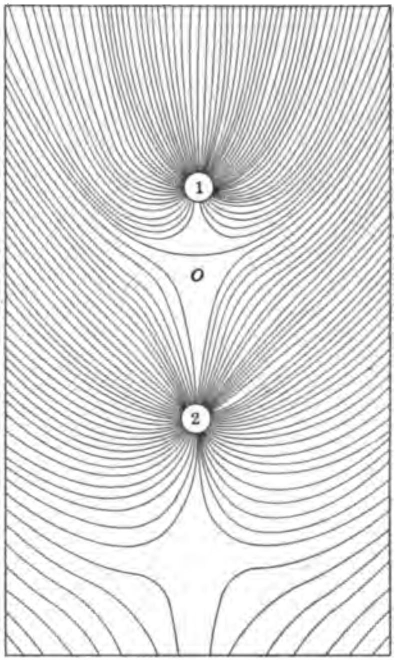


FIG. 137.—Lines of flow into two interfering wells.

The famous Triumph pool in Pennsylvania is a historic example of wells pumped at less than atmospheric pressure.[1] The gas pumps kept from 10 to 12 lb. vacuum on the sand at all times, thus relieving the pressure sufficiently to allow the recovery of the oil. In such pools as this, if conditions permit, air holes drilled at strategic points and left open would undoubtedly result in the flow of oil toward the pumping wells, without the added expense of gas pumps. In other districts where recovery is small, a like procedure would be a profitable means of more

[1] J. F. CARLL, "The Geology of the Oil Regions of Warren, Venango, Clarion, and Butler Counties," *Second Geol. Survey Pennsylvania*, **3** (1880), 260.

rapid recovery, if proper care were exercised. It is, however, true that in many wells air reaches the oil-sand between the bottom of the casing and the end of the tubing, and that by connecting a vacuum pump to the casing the flow of oil is increased.

The so-called "Marietta plan" is based on this principle. By this, air is forced into alternate wells under pressure, while other wells are pumped for oil, sometimes under vacuum. This process has met with considerable success in localities where the sand is of a close uniform texture. In certain coarse pebbly sands there would be a tendency for the air to "short-circuit," and hence be very inefficient in forcing the oil from the sand. As

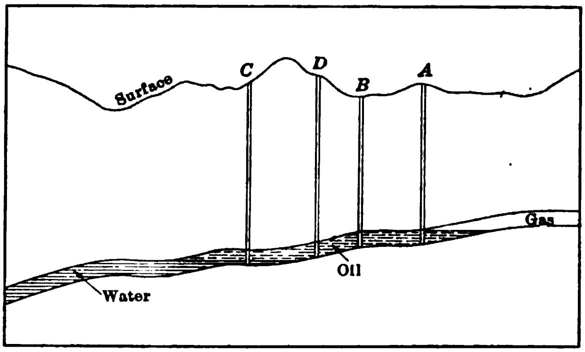


FIG. 138.—The effect of the movement of oil and the exhaustion of oil sand on the yield of wells.

early as 1904, one company installed a large blowing plant in connection with their wells at Batson, Texas.

In some regions where the dip of the rocks is steep, as on pronounced anticlines or monoclines, the action of gravitation on the flow of wells is noticeable, and those wells located up the dip will tend to drain the oil from those lower down. Rival producers, in locating their wells, take advantage of this action. The best practice is, of course, to space wells closer across the dip than in the line of the dip. Fig. 137 illustrates the lines of flow into two interfering wells in a region where the dip, and hence the gravitational movement of the oil, is in a general direction.

Figure 138 also illustrates this condition. As part of the oil is drained from the pool by wells, the remaining part tends to move down the slope of the sand, lowering its upper level so that wells located up the dip (as well *A* in the figure) cease producing,

some of them probably developing a small gas production. As this action proceeds, a well farther down the dip (as well *B* in the figure) will begin to fail, until a well located as at *C* will be the only producer and hence the longest-lived well in the pool.

DECREASE OF OIL SUPPLY ON ACCOUNT OF NEAR-BY DEVELOPMENT

In those pools in which the decline has been normal, with a maximum recovery of the oil, decline in production will depend only on the exhaustion of the gas pressure and the decrease of the available underground supply. Advantage is sometimes taken of natural forces that tend to conserve the expulsive energies of the petroleum in the rock, thus preventing the formation of excessive obstructive sediments and eliminating water problems until later in the life of the well. The character and porosity of the oil rock affect the extent of the drainage, the most favorable material for rapid drainage being a sandstone that is coarse and porous, though not loose enough to allow the setting up of sharply defined drainage channels by the flow of oil and water through the sand. On the other hand, more sudden gas expansion takes place in such a sand than in one of a close texture; and if the oil becomes chilled, wax will form unless care is exercised.

The decrease under consideration occurred at the Petrolia, Oil Springs, and Bothwell pools in Ontario, the wells in those pools exhausting from the outward edges of the productive area inward. The famous Glenn pool of Oklahoma is an example of a different type, the oil-sand being coarse, porous, and uniform in texture, there being no water problem and no excessive waxing of the sand face or the pumping rods. Pumping is regular and consistent, and the wells as a rule are uniformly spaced. As a result, the decline is normal and gradual, the fluctuations in the production of a group of wells occurring only at times of cleaning or as a result of unfavorable pipe-line conditions. Curves 3 and 4 of Fig. 139 represent nearly ideal production curves of groups of wells in the Glenn pool, Oklahoma.

There have been oil wells and gas wells that increased their production for a time after a neighboring well had been completed. In the Mansfield district, south of Shreveport, La., both pressure and volume of some of the pioneer gas wells increased greatly for the first few months. The increased production in

such cases is probably due to the cleaning out of seepage and drainage channels in the rock as a well is drawn upon. Although one well had an initial pressure of 60 lb., which increased in four

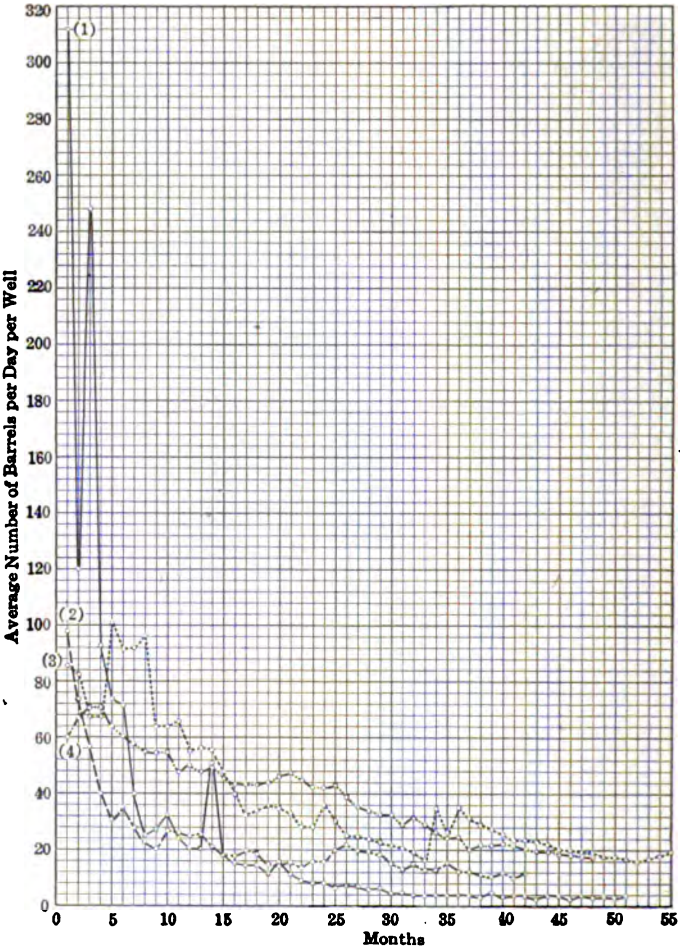


FIG. 139.—Typical production curves of wells in the Mid-Continent oil field. Curves represent production under leases as follows: 1, Muskogee district, Oklahoma; 2, Bartlesville district, Oklahoma; 3 and 4, Glenn pool, Oklahoma.

months to more than 250 lb. closed pressure, yet if the well had been closed for a sufficient length of time to allow the full pressure to accumulate in the casing, the initial pressure would probably have equaled that recorded later. Such wells are usually evi-

dence that the drilling has been done near the edge of an oil or gas pool and not in the best place. Carll[1] states that as a rule the first wells drilled in a new pool have greater productiveness than those drilled later; but that if the first wells are drilled at the edge of a pool in poor rock, wells subsequently drilled at the center of production will drain the pioneer wells, whose high initial yield is largely due to the original rock pressure being sufficient to counterbalance the effect of the tight, close sand.

As illustrative of the conditions mentioned, Carll[2] cites the National well No. 1, drilled in February, 1866, and situated a few rods from the National No. 2, in the Pleasantville district.

> It was very near the edge of a large and well-stored pool and passed through rather an inferior oil rock, as compared with that afterward found on the axis of the belt; still it had a sufficiently free connection with the supplying reservoir to furnish a delivery of about 85 bbl. per day, and it maintained its production with wonderful constancy for two years, having declined only to about 60 bbl. in that time. In the summer of 1868 wells were drilled in the main pool from which it had been deriving its supply. Some of these wells produced as much as 150 bbl. per day. The effect upon the National was immediately apparent. Its production dropped off rapidly and dwindled down to 10 bbl. or less per day.
>
> The Harmonial well No. 1 was on the northern edge of the Pleasantville belt. The main body of oil and the best sand rock, as was afterward demonstrated, lay to the south. It started with a small yield and at the end of a fortnight was pumping about 30 bbl. per day. Gradually increasing its production, as if enlarging and cleaning out the passages leading into the supplying reservoir, it finally commenced to flow and ran up to 125 bbl., where it remained until wells of larger flow were drilled in the center of the belt and relieved the gas pressure, when pumping had to be resumed. After this it soon fell down to an unremunerative production and was abandoned.

Figure 138 shows oil occurring on a monoclinal dip, above a water-saturated zone in the sand. The water level is considered as practically nonencroaching. As the oil body shrinks, owing to the pumping of the wells, the upper level will drop, and wells situated as at *A* will fail, possibly developing a little gas production, followed by the failure of wells, as at *B*. Mean-

[1] J. F. Carll, "The Geology of the Oil Regions of Warrèn, Venango, Clarion, and Butler Counties," *Second Geol. Survey Pennsylvania*, **3** (1880), 259.

[2] J. F. Carll, *ibid.*, 258 and 259.

while a well, as at *C*, is probably pumping somewhat more water with the oil than are the others, and may perhaps be entirely flooded, leaving wells situated, as at *D*, as the longest-lived wells in the field.

The position of an oil property with respect to producing territory should be studied carefully, for the knowledge to be gained from such study will be of much assistance in arriving at a fair valuation of the property.

Practically, so far as the oil man is concerned, an oil-bearing rock before being drilled may be considered as a "sealed reservoir;" and as oil and gas are recovered from it, their places will always be taken by some other medium, as nature tends to restore equilibrium. This replacement may be made by the expansion of gas from the same formation, or by air admitted through wells; but in most fields this replacing agent is salt water from the same stratum, fresh water from the surface seeping through old wells, or water entering from an overlying formation through badly packed or carelessly plugged wells.

Carll[1] says in this connection:

> The flooding of an oil district is generally viewed as a great calamity, yet it may be questioned whether a larger amount of oil cannot be drawn from the rocks in that way than in any other; for it is certain that all the oil cannot be drawn from the reservoir without the admission of something to take its place.

This something may be gas or water from the surrounding rocks or air entering through older wells.

DECREASE DUE TO ENCROACHMENT OF SALT WATER UNDER HIGH PRESSURE

Encroachment of salt water takes place relatively quickly under the following conditions:[2] If salt water lies in the lower part of a porous formation overlain by the oil, and this in turn by the gas above, and if a well taps both the oil and the water, but not the gas because it is all up the dip, expansion of the gas, acting downward on the oil and on the water, causes them to rush to the well outlet. If the water is in greater quantity than the oil, it will often in a short time flood the well entirely. The

[1] J. F. Carll, *ibid.*, 263.

[2] On water in oil wells, see also McLaughlin, *Min. Sci. Press*, **102** (1911), 295.

oil is thus lost beyond recovery, and the well continues to produce nothing but large volumes of water. In pools like the Bird Creek and certain other northern Oklahoma pools, the initial wells were abandoned in some parts of the district, whereas, after the gas pressure had been diminished as a result of drilling other wells, it would have been possible to have pumped oil from the top of the sand without being troubled by water, because the water would then have been under less pressure.

True encroachment to restore equilibrium may occur in a field where there is a strong hydrostatic head counterbalanced by the gas pressure existing in an oil pool, or by a corresponding head of

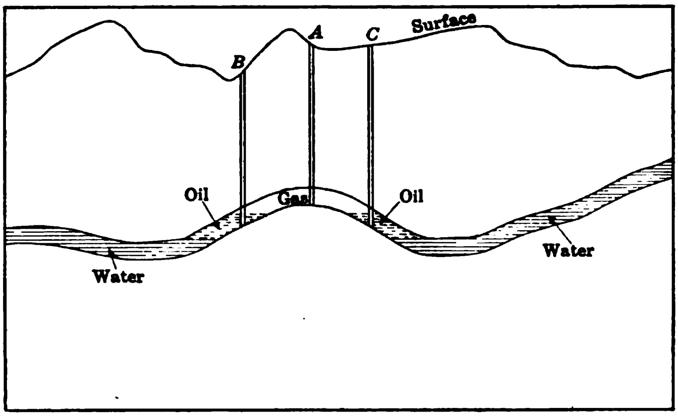


FIG. 140.—How true encroachment occurs.

oil, as shown in Fig. 140. As the gas is drained through well A, the water advances until wells B and C are flooded, and the pool fails from its outer edges inward until possibly well A produces a little oil along with some water, and in its turn is finally flooded.

By studying the direction of flow of encroaching water, certain wells can sometimes be reserved to be pumped for water alone, thus protecting the others of the group or pool from encroachment. Where a few large operators control production in a certain pool, cooperation in the study of such conditions and concerted action may result in a larger recovery of the oil in the pool than would be had by any other means. When many small operators are drawing from a pool, water encroachment is seldom made an ally instead of an enemy.

As a result of the encroachment of water part, of the oil is crowded into the roof of the porous formation, and part advances ahead of the water, changing the relative status of the remaining wells with regard to the rest of the pool, and perhaps materially changing the shape and position of the remainder of the pool. The oil crowded into the roof of the formation or caught in

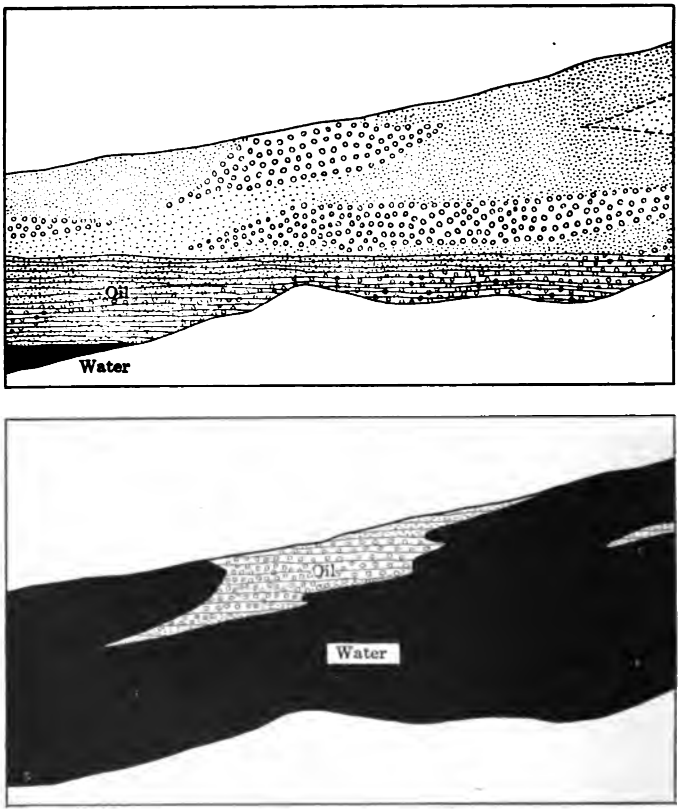


FIG. 141.—The effect of water encroachment.

"crowns" or irregularities causes some water wells to continue to produce a little oil with the water, even though all the surrounding wells produce only water. This condition is illustrated in Fig. 141, which shows a pocket of oil retained by a porous lens in the sand after the encroachment of water.

Salt-water encroachment may also occur where the oil acts as the only force to restrain the encroachment. As wells are

pumped, drainage channels are set up in the sand, and water begins to follow the oil as the oil seeps toward the wells, until only water wells exist. This form of encroachment is really a modification of the second case mentioned above, but can be more easily utilized to aid in draining a pool effectively.

Again, considering the oil-sand as a "practically sealed reservoir," obviously something must be introduced to take the place of the oil that is being pumped out. A body of water under moderate pressure behind the oil will probably aid in moving the oil toward the wells as they are pumped, and will result in the least possible amount of oil being left behind in the formation when the pool is finally abandoned.

DECREASE DUE TO FLOODING BY NONENCROACHING SALT WATER

The occurrence of water in the lower part of the same porous formation in which the oil is encountered is frequent in pools where the rocks lie almost level. Where such a condition exists, care is usually exercised to stop drilling just short of the water. However, an uneven formation may make it impossible to judge with certainty when to stop drilling. Possibly cleaning or shooting a well may cause it to break through into the water below, or an influx of fresh water from the surface or from an overlying formation may raise the water level above that originally existing in the oil-sand. In such cases oil and water are pumped together and in many cases the total amount of water decreases in the course of time. However, certain classes of mineral water tend to "cut" the oil and cause the formation of obstructive matter. It is believed that in some pools pumping the water with the oil is an aid to the oil recovery, the water tending to "flow" the oil toward the well.

In Oklahoma the high gas pressure in the early days of some pools has blown out such large quantities of water with the gas that many wells have had to be abandoned. When the pressure in such wells has decreased they may be pumped to advantage and may produce oil in large quantities; or by keeping the pressure of the gas as a restraining agent, by using only a small percentage of the capacity of the well, the water may be kept back and oil only recovered.

DECREASE DUE TO FLOODING BY FRESH WATER

Owing to defective packers, to lack of care in plugging abandoned wells, and to accidents in drilling and casing, water is admitted to many oil-bearing formations from the surface or from an overlying water-bearing stratum. Depending upon conditions, this admission of water may have any one of several results.

If the volume of water is small, such as that seeping around a defective packer, or that due to temporary flooding before the packing is inserted, it may aid in the recovery of the oil by furnishing the medium necessary to take the place of the oil pumped out, thereby increasing the production of a well or group of wells.

If the quantity of water is large and the thickness of the porous formation is small, the water may force the oil back so far that it cannot be recovered from the well affected. The inflow of water may, however, benefit other wells in the vicinity, helping the movement of the oil in other directions, and, the field being considered as a whole, may replace the oil pumped out and aid in its recovery. The pressure exerted by the column of water in a deep well is great, especially if the volume of water entering the well is sufficient to keep the column constant.

The flooding of fresh water no doubt accounts for some phenomenal production in fields where the recovery of petroleum from a sand rock has been relatively much higher than in other districts producing oil from a formation of equal thickness and porosity.

Attempts have been made to flood an oil-bearing formation, so as to concentrate the oil in the formation and to effect a maximum recovery of the oil by water replacement. The practice is denounced by old operators in the Bradford (Pa.) field, and these efforts have met with indifferent success, not on account of fault in theory, but on account of insufficient data bearing upon underground conditions, varying porosities, etc., making intelligent prediction as to the movement of the oil an uncertainty. Clashing interests usually prevent such attempts on a large scale, wells belonging to rival operators being perhaps the first flooded, although they may not be located so closely as other wells.

When water is admitted in large quantities it tends to flow out

in various directions, the greatest flow following the line of least resistance. Owing to the differences in the resistance offered by sands of differing porosities and to varying amounts of gas in the rock, this movement of the water (and oil) in regions of low monoclinal dip—say, 15 to 20 ft. to the mile—will extend up the dip as well as down. The movement will be particularly strong in the direction of very porous lenses and toward pumping wells, regardless of the effect of gravitation, the suction created by the pumping wells being sufficient to overcome the relatively slight tendency of the fluid to flow downward. This effect sometimes causes wells situated above the point of flooding to be affected ahead of the water wave and abandoned before those down the dip are affected. As an additional result, the water wave, aided by irregularities in the structure and shape of the pool, will sometimes surround bodies of oil that were originally a part of the pool. Two or three such isolated pools are mentioned by Carll as having been discovered on the outskirts of the Pithole oil pool after the central part had been flooded.

Again, lenticular pebble beds or lenses of unusually porous sand may form pockets in the upper part of an oil-sand and may catch quantities of oil, which are retained as the main body of oil advances ahead of the water wave (Fig. 141). These pockets furnish the oil in many wells that are entirely surrounded by flooded territory yet continue to produce a little oil along with large quantities of water.

The entering water may shift the whole body of oil from its original position, the extent of such shifting depending on the dip and shape of the pool and its underground structure. The Oil Springs pool in Lambton County, Ontario, is an example. When the pool was first developed it produced from a shallow "pay," an open vesicular stratum in the Corniferous limestone. The wells were all dug and were cased with Scotch casing of large diameter. At the time of the Fenian raid, the field was temporarily abandoned. When operations were later resumed it was found that the lower part of the casing in a great number of the wells had been corroded away, the wells had caved, and great quantities of fresh water from swamps on the surface had flooded the oil-bearing formation. Deeper drilling developed the present "pay" stratum at a lower depth, and the old wells were abandoned, as they could not, of course, be plugged.

In recent years wells drilled through this shallow stratum

showed that the water had decreased, and one well struck oil. Other wells were drilled, and an attempt was again made to pump off the water.

These operations developed the fact that after the spring rains or any large freshet, quantities of fresh water seeping into this porous formation caused the water level to advance up the sides of the anticline upon which the pool is situated, carrying before it a considerable body of oil. By pumping certain wells, located at strategic points, in progressive rotation as the water or oil advanced or receded, considerable oil was recovered.

It was noticed that more oil was recovered upon the recession of the water than upon its advance. As the water advanced, a part of the oil was probably caught and retained in the porous irregularities on the roof of the stratum. As the water receded, these were again taken up by the main body of oil, increasing its quantity. This supposition is supported by the fact that a few wells would continue to produce a little oil with the water after the surrounding wells had all been flooded by the advancing water. This theory is illustrated in Fig. 136. 1 and 2 represent wells through which flooding takes place, whereas A, A', B, and C represent wells pumped successively for oil as the water changes the relative position of the oil body.

One well is reported to have yielded 1,300 bbl. of oil in three days before failing. As these shallow wells must be worked at great speed to effect a maximum recovery before being again flooded, pumps of large diameter and quick stroke are used.

Owing to the unusual conditions and to the open vesicular nature of the oil-bearing stratum, the effects of flooding could be observed to good advantage in the Oil Springs pool. In most pools the "sand" is less porous, seepage and movement of the water and oil are slower, and local conditions complicate the problem.

The main factors affecting the flooding of an oil-bearing formation may be summarized as follows (adapted from Carll):[1]

(*a*) Time of flooding—whether early in the process of operations, while yet a large percentage of oil (and gas) remains unexhausted, or at a later period after the supply has suffered from long-continued depletion.

[1] J. F. Carll, "The Geology of the Oil Regions of Warren, Venango, Clarion, and Butler Counties," *Second Geol. Survey Pennsylvania*, **3** (1880), 265.

(*b*) Composition of the formation—whether regular and homogeneous throughout or composed of fine sand interbedded with irregular layers of gravel, in places lying near the top and in places near the bottom.

(*c*) Position of the pool—whether flat, as on a structural terrace, upon a monoclinal slope, upon the crest of an anticline, or at the bottom of a syncline.

(*d*) Shape of the area being flooded.

(*e*) Position of the point at which water is admitted in reference to the situation of surrounding wells still pumping oil.

(*f*) Height of the column of water obtaining admittance.

(*g*) Duration of the water supply. It will readily be seen that a temporary flooding in comparatively fresh territory, as from the drilling of new wells without casing and from the overhauling of old ones having the seed bag attached to the tubing in the primitive way, must necessarily be a different affair from a flooding caused by a permanent deluge through unplugged and abandoned wells in nearly exhausted territory.

In the former case the flood may be checked before much water has accumulated in the rock, and then the oil flow can be reclaimed after a few days of persistent pumping; and in the latter the recovery of oil is very uncertain, because, for its long-continued extraction, a greater capacity has been given to the rocks for storing water, and this being supplied from scattered and obscure sources there is little probability that it can be shut off, although the most thorough and systematic attempts be made to check it.[1]

Mention may be made of the danger of drilling wells off shore along large bodies of water, as has been done in the Selkirk gas field in Ontario, along the California coast, and in the Tumbes oil field in Peru. An unlimited quantity of water, once admitted, will result in the flooding of an entire district.

On the other hand, the continuous entrance of relatively small quantities of water through leaky seed-bag packers in the early days of the Pennsylvania oil fields may have furnished the heat necessary to prevent the chilling of the oil that was expelled through the free escape of large quantities of gas. The water so entering may have accounted for the continued productiveness of some wells, preventing the chilling of the oil and the

[1] J. F. Carll, *ibid.*, 266.

formation of waxy sediments, and may have been one of the factors in some of the phenomenal productions of that period.

Although in drilling wells by the old wet method[1] the heavy column of water may have prevented the early discovery of some oil-bearing strata, nevertheless the gas was conserved until utilized in the expulsion of oil. Some modern wells drilled by the dry method, all water being cased off while drilling is under way, encounter, especially in the Oklahoma fields, a strong flow of gas, which is blown off before the expulsion of oil commences. Were these wells drilled "wet", there is no doubt that in some cases this premature blowing of gas would be avoided, the oil would commence to flow immediately upon pumping out the water, and the rock pressure of the pool would be conserved for the continued expulsion of oil, thus increasing the ultimate production of the district. This great waste of natural gas is one of the extravagant practices and one to which little attention has been paid until now, when the fields are on the point of exhaustion.

DECLINE DUE TO THE DRILLING OF NEIGHBORING WELLS

In an oil pool situated in a region where the formations have a pronounced dip, it will usually be found the best practice to space wells closer across the dip than down the dip. Figs. 137, 142 and 143, from Slichter's[2] discussion of the mutual interference of artesian wells, show a number of ways in which oil and water are diverted by wells, either flowing or pumping. Fig. 142 shows the lines of flow into a well in a region where the fluid has a constant motion in a general direction. If a second well were drilled in the neutral zone, *O*, its production would be considerably smaller than that of well 1. This figure, in connection with Fig. 137, will indicate the advisability of spacing wells closer across the line of dip or flow than down the dip. In the West Virginia fields, and in a few Oklahoma fields, where operators control large blocks of territory, wells are being spaced one well to 10 acres. In many fields the practice has been to space them much closer than this; and in many town-lot developments, several wells have been drilled on an acre.

[1] Isaiah Bowman, "Well-drilling Methods," *U. S. Geol. Survey, Water-Supply Paper* **257** (1911), p. 51.

[2] C. S. Slichter, "Theoretical Investigation of the Motion of Ground Waters," 19*th Ann. Rept. U. S. Geol. Survey*, pt. 2, **1898**, 367.

Slichter[1] demonstrates that in water wells in homogeneous formations, the total flow of two wells 200 ft. apart is about 169 per cent. the flow of a single well. If a third well be placed midway between the two, so as to make a row of three wells 100 ft. apart, the total combined flow from the three wells is about 207 per cent. of the flow of a single well. On the basis of relative viscosities of light crude oils and water, the same figure

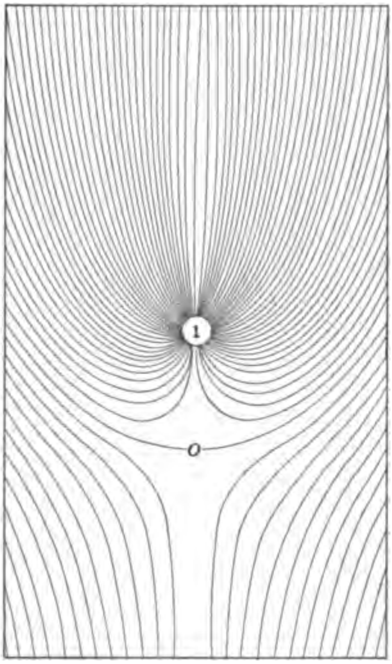


FIG. 142.—Lines of flow into a well in a region where the water or oil has a constant motion in a general direction.

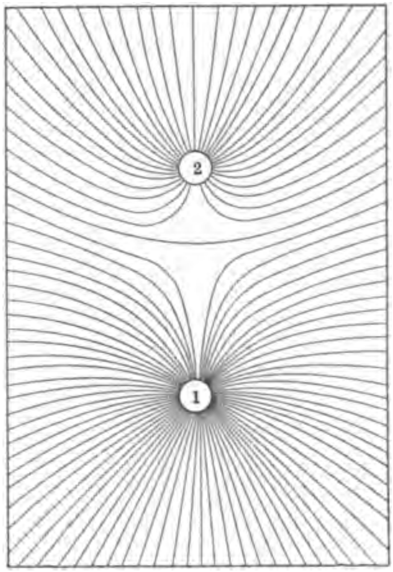


FIG. 143.—Lines of flow into two interfering wells, one of which has double the capacity of the other.

would apply approximately to oil wells 400 ft. apart. This disregards differences in the porosity of the sand, varying gas pressures, etc. In a normally tight sand, wells may be drilled closer together in order to drain the territory at the same rate, the character of the sand preventing excessive refrigeration due to the free escape of the gas. In such a tight sand neighboring wells do not affect each other to the same degree as in a very

[1] C. S. SLICHTER, *ibid.*, 377.

porous stratum; that is, such pronounced drainage channels toward the wells first drilled are not formed.

Figure 144, after Hager,[1] indicates how the first well (1 in the figure) drilled in loose unconsolidated formations, such as the Tertiary and Cretaceous sands of California and Louisiana, will set up drainage lines in all directions, so that later wells (2, 3, 4, and 5 in the figure) will produce little or nothing, although there are still large quantities of oil in the field. Well 1, however,

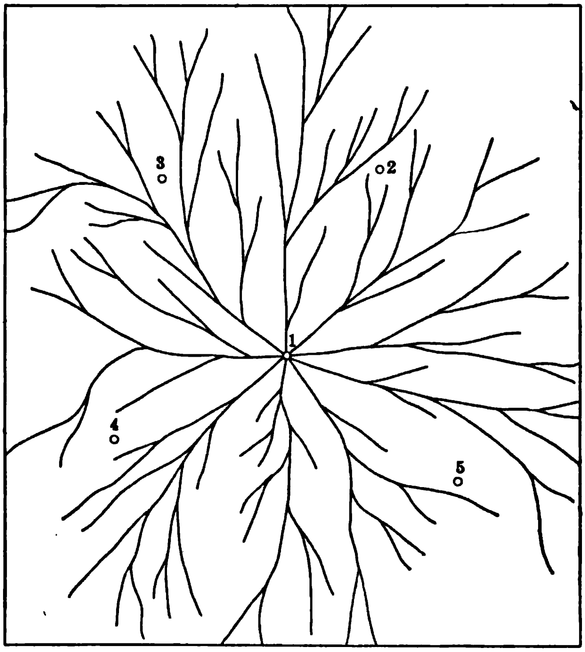


FIG. 144.—The drainage lines of one well.

continued to produce prolifically. Fig. 143 shows the lines of flow for two interfering wells in the case where one well has doubled the capacity of the other, the larger presumably having been drilled first.

Town-lot development and the conditions brought about by many operators with small leases fighting for production, result in extravagant and wasteful methods of production. Likewise, in the case of the Government leases in Oklahoma—the so-called

[1] DORSEY HAGER, "Geological Factors in Oil Production," *Min. Sci. Press*, **103** (1911), 740.

"short-term" leases—operators were led to drill uneconomically in order to extract the maximum amount of oil before the leases expired. Such development means uneconomical production throughout—drilling more wells than are necessary, pumping too fast, wasting gas pressure (and the gas itself), in flooding wells, and pumping one well against another, thereby creating underground conditions favorable for the encroachment of water.

To drain an oil property most efficiently, that is, to extract all the oil possible with a maximum number of wells and at an economical rate of production, it is essential to consider the best distance at which to space wells. This distance will, of course, differ for every producing stratum and for every field.

In a great many fields the territory is divided among a number of operators, each working against the other to extract the most oil possible before his neighbor has a chance to take it. This usually results in the holders of small leases drilling as many wells as possible close to the boundary lines, forcing the lessees of surrounding land to drill well for well in order to protect their own property. As a matter of course, in such cases, no attention is paid to the proper spacing of wells, nor to the probable effect of one well on another. When large operators control sufficient acreage, the common practice in the older fields is to space wells from 400 to 500 ft. apart. The relatively large leases in the Cushing pool, in Oklahoma, has made it possible for operators to drill more efficiently than was the case in some parts of the Glenn pool. The average in the Cushing pool is one well to 8 acres. This has saved a great deal of money for unnecessary drilling operations, and also undoubtedly conserved more favorable underground conditions in the field.

As mentioned above, in some formations the first well drilled in a group will tend to set up drainage channels and divert large quantities of oil from a considerable area. Subsequent wells come in as much smaller producers than the original well. Again, in loose, unconsolidated sands, such as are found in the Caddo field in Louisiana, in California, and in the famous Glenn pool in Oklahoma, if a well stops pumping for a day, the surrounding wells extend their own channels, breaking down the drainage system of the first well, to the extent that it is often difficult to again recover oil from the well that has stopped pumping. As a result, the wells in the Glenn pool are pumped 24 hr. a day, 365 days in a year. The condition of the sand in the Glenn pool

was brought about somewhat artificially by the use of enormous quantities of nitroglycerin in shooting. The sand, originally coarse and porous, has probably been shattered throughout the entire producing area.

In certain lenticular formations, described by the oil man as "spotty," of two wells drilled only 150 ft. apart, one has been a large producer and the other a dry hole. This discrepancy may be due to drainage conditions or may be caused by an intervening hard spot in the oil sand. If it is caused by drainage conditions, the stopping of the producing well would probably cause the other to produce. Again, wells 1,000 to 2,000 ft. apart are in places so closely connected underground that the muddy water used in drilling one well has been pumped out by another well a considerable distance away, not necessarily the well nearest to the one being drilled. This condition is common in the Caddo field in Louisiana, and in other fields producing from the unconsolidated gravels and sands of the Cretaceous and Tertiary formations.

In a previous paragraph is mentioned a case in the Vinton pool in Louisiana, in which a well drilled near a good producer encountered a loose, coarse pay sand. In the producer the sand was so loose that the rotary bit of its own weight immediately sank to the bottom. The second well struck sand, seemingly of the same nature, which immediately "packed," so that drilling was necessary to penetrate it. The second well never produced; moreover, the sand "packed" in the original well, which likewise ceased to produce.

The Triumph pool in Pennsylvania was operated by means of gas pumps, so that there was a minus pressure of 10 to 12 oz. at each well.[1] It is possible that the Vinton pool, which is a small isolated pool in which all the wells drilled were producers at the time mentioned, was being operated under similar circumstances. There being no water to take the place of the oil extracted, when the second well was drilled, the sudden application of atmospheric pressure was sufficient to pack the sand and force the oil in the vicinity to other parts of the field where wells were being pumped. The oil is of a heavy asphalt base, with no gas content, and no water was encountered.

[1] J. F. Carll, "The Geology of the Oil and Gas Regions of Warren, Venango, Clarion and Butler Counties," *Second Geol. Survey Pennsylvania*, **3** (1880), 260.

It is possible that the sudden flooding of some oil pools is occasioned by the drilling of a well into the water at a strategic point, thus putting an added pressure of 15 lb. per square inch behind the water, which perhaps lacked less than this amount of the force necessary to flood the oil-bearing district. Such a balance of forces would of course be rare and difficult to anticipate. Possibly a series of water wells, drilled from time to time as the pressure in an oil pool diminished, might reduce the rapidity of the flooding and yet be the direct means of flooding the oil-producing wells. However, the writer knows of no instance where such a procedure would have been warranted in practice.

Again, the production of wells in pools producing heavy oils with little or no gas pressure, such as some small pools situated on quaquaversal domes along the Gulf coastal plain, might be increased by drilling air holes on the outskirts of the pools, thereby creating a draft from these points to the wells located in the center of production. If this should be done in pools situated in flat-lying strata or on very slight dips, the use of the gas pump to aid small wells might be avoided in some instances, the atmospheric pressure creating a flow of oil. This plan would at least be safer than an artificial flooding with water, if the underground conditions are practically unknown.

DECREASE DUE TO POOR MANAGEMENT

Many wells cease to produce at an economical rate because of poor management of the numerous mechanical details. Some of these are enumerated below, but it may be said that it is in the surface management of wells that greatest improvement has taken place since the early days of petroleum production. In fact, it is remarkable to consider the great variety of time- and labor-saving contrivances now in use, as against the great dearth of information regarding underground conditions.

Neglected Casing.—Casing corrodes more in some districts than in others. It is often allowed to deteriorate without attention, until the result is the admission of water to the productive stratum from overlying formations or from the surface. This cause of decreasing production needs only the simple remedy of proper attention.

Pumping Methods and Regulations.—In most fields where producing wells are closely grouped, as many of them as possible

are pumped from a common power plant by "shackles" or "jerk lines." Some of the wells may be pumping from several different producing formations at the same time. Especially in the high-grade oil fields each well requires different handling, and the rate and the length of time for pumping most effectively at one period of its life will not produce the best results at another. Although this variation is obviated to some extent by the use of "bleeders," "leaky valves," and other devices for automatically stopping the pumping of oil before the face of the sand is uncovered, yet such regulation is unsatisfactory and leaves much to be desired. "Pumping by heads" is a step in the right direction, in that it conserves the gas pressure in the pool for the continued expulsion of oil and also tends to keep back salt water under pressure. However, under present practice it is impossible to judge the best possible time to pump and the proper height of oil column to leave in the well at all times. An automatic control, with valves set to start pumping upon the accumulation of a certain maximum pressure, and to stop pumping upon the exhaustion of the oil to a certain set depth, would add greatly to the production in many cases, and would eliminate the possible negligence and usual lack of knowledge of the average pumper. Several automatic control devices are said to be on the market, and one at least has been tested with success. The problem of applying them is solely mechanical, and there can be little question as to the advisability of the use of such devices at a great many wells.

Incorrect pumping methods, by which a well is pumped too fast or too often or too deep, produce several bad results. The expansive force of the gas and its aid in the movement of the oil is lost by the gas being allowed to escape freely. Instead, only such an amount of gas as is associated with the head of oil pumped should be allowed to escape.

The ideal cycle of production in a pumping well very closely approximates that of a well packed by the old seed-bag method, as follows (adapted from an unpublished manuscript by M. W. Quick):

(*a*) Pressure is developed in the well sufficient to overcome the resistance of the column of liquid in the tubing, which is expelled naturally or pumped off.

(*b*) The weight of petroleum in the well column overcomes the rock pressure and a point of equilibrium is reached. The

excess of pressure of the shut-in gas over that of the column of oil has only a slight retarding effect on the further expulsion of oil, as the shut-in pressure can never exceed the rock pressure.

(*c*) The pump is started and the "head" of oil above the top of the sand is pumped off and the shut-in gas is allowed to escape. Thus the only gas released is that originally in the head of oil, where it aids in expelling the oil.

(*d*) The well is again shut in and again heads. Although such control is practically impossible where the pumping of a well is regulated by ordinary methods, yet an automatic device for such regulation would result in the maximum recovery of oil with the least possible loss of expulsive energy from the stratum. To duplicate this cycle, pumping methods must be controlled by intrastrata conditions in some automatic manner, otherwise wells will be pumped too frequently to insure the greatest production. The resistance of chilled oil may not be overcome between the pumping of accumulated heads of oil, and energies for the expulsion of sediments and waxy accumulations may not be developed.

Automatic devices are on the market; but owing to the inertia of the producer relative to trying out such seemingly revolutionary schemes, they have not been given a fair trial under the conditions to which they are adapted. A general recognition of the need of such automatic control for the pumping of oil wells, governed by the natural underground conditions at each well, would result in the perfecting of many details to adapt the devices to the varying needs of different fields. Thus the production of districts now being abandoned, with large quantities of oil still remaining in the rock, would be increased. The requirements of each well vary and the necessities of to-day will not apply to-morrow. Conservation of rock temperature to prevent chilled and "cut" oil, by the use of head pumping, bleeders, or leaky valves causing the flooding of the sand and reducing refrigeration of the gas by expansion, is necessary in the fields producing high-grade paraffin oil. It is not so necessary in the Mexican and other fields producing heavy oils that contain less spontaneously volatile hydrocarbons. Conditions of accumulation are also very different in the Gulf Coast and Mexican fields. High-grade gaseous oil containing high percentage of paraffins, must, of course, be handled differently from the heavy oil of the fields last mentioned.

The flowing of wells by compressed air is falling into disuse in the Eastern and Mid-Continent fields, as it has a tendency to cut the casing of the tubing. Flowing is not economical for small wells, there not being a sufficient head of oil against which the air may act. The effect in practice is to increase vaporization and the formation of waxy sediments and to clog the face of the sand.

Air-lift pumping has been tried with the same effects as regards increasing the chilling of the oil and the formation of paraffin. These methods are both more applicable to heavy oil of an asphalt base.

Construction of Wells.—Increased production may sometimes be obtained by using large casing. This makes possible the use of large strainers where desirable, and the use of an inside perforated casing or liner where the formation is inclined to cave and cause the casing to collapse; in fact, the large-sized holes make the future handling of the well, or future deeper drilling, an easier problem. It may be said that wells that might flow naturally with a small-sized casing would cease to do so through a large hole. This difficulty is sometimes overcome by using a reducer on the bottom of the lowest string of casing, the well flowing through a 2-in. tubing for a long period after it has ceased to flow with only the 5$\frac{3}{16}$-in. casing in the hole. The larger hole has a tendency to drain the territory more quickly, and consequently the well will very probably be shorter lived than if the hole were smaller in diameter. Also, the larger hole probably results more frequently in chilled oil, caused by the greater surface from which volatilization occurs. Enough information has not been gathered to give definite figures as to this.

Tapping all Overlying "Pay" Strata.—In the early development of new fields, in the hurry to tap the principal oil stratum in advance of rival operators, all overlying "pays" are neglected and usually are cased off, no record of them being kept by the driller, who is usually paid for drilling by the foot or by the well. In later years, when production has fallen off in the older sand, it often becomes desirable to tap the upper sands, but by that time it is frequently impossible to know how deep they lie. In drilling by the wet method in the early days, the water pressure prevented some minor oil "pays" from indicating their presence. These have since been developed and some of them have proved large producers.

Deep Drilling.—Improved methods of drilling, a better knowledge of the geology of oil and gas, and the rapidly increasing demand for petroleum, have recently resulted in a search for petroleum by deep drilling in many of the older fields, some of which are enjoying a new lease of life—notably parts of the Clinton sand fields of eastern Ohio, the St. Mary's pool in West Virginia, and some of the Pennsylvania fields. It is considered not improbable that the Mid-Continent fields have a deep-sand future.

Spacing Wells.—In spacing wells, the utilization of the movement of the oil in a pool and the thorough draining of the maximum amount of territory with the minimum number of wells, are the two main considerations. As regards the first, as has been mentioned, the wells should be spaced closer together across the dip of the formations than down the dip, or in the direction in which the oil is draining. In any given field advantage should be taken of all available data bearing on the effects of wells on each other at different distances and in different directions. Hager[1] gives an interesting method for obtaining data regarding the proper number of wells necessary to drain a certain given territory, in the California fields, as follows:

The property, 640 acres, is underlaid by three sands. The table below shows the known and the computed information prepared from a study of a large number of wells.

TABLE XXXVIII.

Area underlain by sands. 1	Thickness of sands under each acreage. 2	Number of acre-feet. 3	Computed quantity of oil available. 4
Acres	Feet		Barrels
200	95	91,000	9,000,000
200	65	13,000	6,600,000
240	40	3,600	4,400,000
640		41,600	20,000,000

Columns 1, 4, and 5 are taken from Table XXXVIII. and correspond to columns 1, 2, and 4, respectively (which are of importance in reaching a conclusion as to the number of wells needed). Columns 2 and 3 in Table XXXIX. are derived from data collected

[1] DORSEY HAGER, "Geological Factors in Oil Production," *Min. Sci. Press*, **103** (1911), 739.

from a study of a large number of wells. Column 4 is obtained by dividing the figures in column 5 by those in column 2. Column 7 is obtained by dividing the figures in column 4 by those in column 6. These results are purely assumptive, and should in no way be considered as of value except for the purpose of illustration.

TABLE XXXIX.

Thickness of sands. 1	Production per thickness in 1. 2	Life per thickness in 1. 3	Number of acres. 4	Computed number of barrels available. 5	Number of wells needed. 6	Acres per well. 7
Feet	Barrels	Years				
95	180,000	9	200	9,000,000	50	4.0
65	120,000	7	200	6,600,000	55	3.6
40	80,000	5	240	4,400,000	55	4.4
			640	20,000,000	160	4.0[1]

As Hager states:

"Every operator desires some idea of the amount of oil he may reasonably expect from a property. Estimates of this kind are only approximate and are useful guides to conservative men."

The above method should be used with care and in connection with all data obtainable as to the location of the property in relation to the rest of the pool; and in estimating the theoretical quantity of oil available from the thickness of the sand, good judgment based on accurate data is necessary to determine the true thickness of the sand as shown by the drillers' logs. In some pools only a part of the porous stratum is saturated with oil, or other prevailing conditions make calculation of the oil content on this basis incorrect. The method could, of course, be used only in territory already proved.

CLEANING WELLS

With regard to cleaning wells, Roswell H. Johnson, of the University of Pittsburgh, makes the following statement regarding the Mid-Continent fields:

I find that there are operators who never clean their wells, those who do so only as a last resort when the well is near abandonment, and

[1] Average.

others who do so periodically. I should say that on an average wells are not cleaned oftener than once in three years. The consideration of this matter is important, because the practice is so variable and the work is so expensive. My own views are as follows:

METHODS OF CLEANING UNDER DIFFERENT CONDITIONS

Where Water is not Found in the Sand.—In case the sand does not carry water, a pocket at least 10 ft.[1] deep should be drilled below the sand. Besides the possibility of revealing a second pay, the pocket provides a receptacle for loose sand or cavings without affecting the well. I would have the intake of the pump opposite the bottom of the pay and have a small air hole in the working barrel near its top at the top of the pay. The first cleaning immediately after the shot should be thorough and should empty the pocket. Such a well, by sanding its pump cups, will automatically show when cleaning is needed. When the pump is pulled for renewing the cups, the depth of the well should be measured with a tape to see how much the pocket has filled. If the filling is more than 2 ft. above the bottom of the pay, it probably will be practicable to clean the pocket; if the filling is less, the working barrel can be set higher until the cups have to be replaced again. Of course, with oil selling at 60 cts., one would not be as intent on cleaning as with oil at $1.50. As soon as a well is in good shape, I think the derrick should be removed and used elsewhere. Pulling is done with a pulling machine and cleaning with a drilling machine. I think the shot should be placed at the bottom of the pay, so that the hole will extend still farther and, with the pocket, give space for a considerable accumulation of loose sand before the intake is reached. When the well becomes unremunerative a working barrel without the air hole may be put in; then the well can probably be pumped a little while longer.

Where there is Nonencroaching Water under Low Pressure in the Bottom of the Sand.—If there is water under low pressure in the bottom of the sand, drilling should be continued until water is evident, and should not be stopped at the depth where water is expected. The pocket should be omitted and the well should be shot at a point only 1 ft. above the supposed line between the water and the oil. The first cleaning should be thorough. Effort should be made to have the well "make" considerable water with the oil, care being taken, of course, not to get so much that a 24-hr. pumping through the 3-in. pipe will exhaust the water, if fuel is cheap. By taking this water, assurance is had that no pay will be missed; also, the current of the water flowing to the hole helps to move in the oil.

[1] In the Ontario peninsula pockets 50 to 100 ft. deep are drilled by the leading operators.

Where there is Nonencroaching Water under High Pressure.—In case there is nonencroaching water under high pressure, care should be taken to stop wells a little short of the water. They may be drilled deeper to the water when it is desired to clean them. In my opinion, many of our wells, deserted because drilled through oil into high-pressure water, could have been handled a year or two later when neighboring wells had reduced the pressure.

Where there is Encroaching Water.—If there is encroaching water, wells must stop a little short of the water; hence the shot should not extend to the bottom.

GENERAL METHOD OF CLEANING

The methods of cleaning in general use may be enumerated as follows:

1. Removal of accumulated sand by tools and sand pump.
2. Hot-billet treatment. Too uneconomic and inefficient.
3. Gasoline treatment. I believe this method is very useful where the refinery owns the well and can thus recover the gasoline.
4. Freshening the hole with a small torpedo. This expedient is not necessary when the sand runs in freely. It is probably most useful where some kinds of water are associated with the oil and make a deposit on the sand face.
5. Electric heat. This seems very promising.

In regard to freshening the hole with small shots, so-called "squibbing," it may be said that the effect is probably to furnish the heat necessary to redissolve the accumulated waxy paraffins that clog the hole and to cause their expulsion by fresh oil. Even though it be conceded that close argillaceous and calcitic sandstones saturated with petroleum require shattering, the conclusion does not follow that all sandstones should be treated with large quantities of high explosives, as shooting often produces a heating rather than a shattering effect. In a hole full of water the liquid takes up the shock of the shot and prevents shattering, yet the shooting results in increased production by causing a fluxing of the waxy sediments.

In other wells "pay" streaks are unknown, but shooting in later years may start them flowing.

CONCLUSION

The spacing of wells, the construction and management of wells, the encroachment of water, the conservation of gas, the cleaning and pumping of wells, are all subjects demanding the

closest attention and the most detailed study at this time, for the reason that the life of the industry depends on the lessening of waste and the proper exploitation of our petroleum resources.

Exact information regarding the yield of wells is meager and unclassified, so that the preparation of an account of the technology of this important branch involves not so much compilation of published data, but rather, to a large extent, the recording of results of extended inquiries in the field. The persons consulted frequently have no conception of the relation of the information they give to the problems under consideration. On the other hand, many producers and operators are improving their methods as a result of experience, realizing that the problems in new fields or new pools cannot be handled by rule-of-thumb methods. Such methods, although excellent for the conditions under which they originated, cannot always be applied to conditions in new fields and to drilling and operating under unforeseen difficulties.

CHAPTER X

EFFICIENCY IN THE PRODUCTION OF PETROLEUM

BY ROSWELL H. JOHNSON[1]

The wisest management of our oil resources demands (1) the production of maximum amounts with a minimum sacrifice of human effort; and (2) the utilization of this product with the maximum satisfaction to ourselves.

The discussion falls under two general heads, increased efficiency in production and in utilization.

Efficient Production.—The present methods of producing oil leave very much to be desired. We may reasonably hope, if proper research is given to the subject, that in the next decade such advance will be made as to secure the product with a decided reduction in drilling expense, and, what is more, to obtain a far higher percentage from the sands that are reached. Unfortunately, current practice fails to make use of even those improved methods that have been already proposed or demonstrated.

Leasing.—The method of leasing to-day is peculiarly wasteful, for the reason that the royalty to be paid to the land owner is a fixed percentage. It is perfectly obvious that as the decline continues, the well must be abandoned when the producer's fraction of the production, for instance, seven-eighths, no longer exceeds the maintenance charge, although the well could still yield more than the maintenance charge, if this one-eighth was not deducted. Some kind of a sliding scale or graduation should therefore be adopted in order to reduce the rate as the well ages. This may be accomplished either by the block, period, uniform or class method.

The block method calls for a fixed royalty rate on all oil produced up to a certain amount, after which a lower rate would be charged. This method is objectionable since the rate is reduced without reference to the decline of the well. It fails to adjust the ability to pay to the amount of payment.

[1] Professor of Oil and Gas Production in the University of Pittsburgh, and member of the firm of JOHNSON and HUNTLEY, Consulting Oil Geologists, 306 State Hall, Pittsburgh, Pa.

In the period method, the royalty rate is changed by some definite amount when the well produces less than a specified quantity per day or other given unit of time. While simple in character, it operates badly because a great deal is made to depend upon a small reduction in production, whereas the reduction, as a matter of fact, declines rather erratically, owing to the exigencies of lease management, connecting of tankage, and the vagaries of the gaugers.

These disadvantages are obviated by the uniformly degressive method. In this method, all the production less than a certain amount per week pays no royalty. The amount paid in royalty declines gradually, rather than suddenly, as in the period method.

The fear has been expressed that if uniformly degressive royalties are adopted, too high a royalty would be charged in the early life of the well, which would have the effect of destroying the occasional high rewards essential to the producer to recoup him for the heavy expenses of the inevitable proportion of dry holes. Such a result would necessitate a great increase in the cost of oil to the consumer to produce higher profits on small wells, in order to stimulate the producer to continue his activities. Such a result would be a social loss; but the fear, in the author's opinion, is not justified, for the land owner would not get such high, early royalties without serious sacrifice in the bonus, which he would usually prefer not to make.

Another advantage of the uniformly degressive royalty is to prevent the excessive flat royalties now frequently offered for promising land, such as the 50 per cent. on the Cimarron River bottoms and the 25 per cent. that we occasionally hear of in other fields. These royalties always lead in a few years to unpleasant threatening and bargaining between land owner and lessee, resulting in successive agreements to reduce the royalty rate. This awkward process, it is true, does accomplish a gradual reduction of the royalty rate. But the asperities of such negotiations are very annoying and sometimes lead to premature abandonment of the well, with a consequent serious offense against wise conservation. The uniformly degressive royalty, while avoiding the difficulties just referred to, still retains a flexibility, by virtue of which the producer, who desires to, may increase the royalty rate when the well can stand it, in this simple way transferring some of the speculative profits to the land

owner in lieu of bonus. This bonus the producer may not be able to pay, or the land owner may prefer not to accept.

The uniformly degressive royalty lengthens the life of the well and increases the percentage of the oil which is recovered. If the royalty is one-sixth and the maintenance and interest on the "junk" is 83½ cts. per day, then a well must be abandoned when its net income to the producer declines to that amount. Yet the gross income is still $1 per day; and if the decline of the well is one-sixth in a year (a common decline in old wells in Oklahoma), it might continue to produce for a year longer, except for the prohibitive royalty. Thus, 300 bbl. per well might easily be saved by a mere royalty adjustment. The Osage Nation is leased at one-sixth, so that all its wells will be abandoned proportionately earlier, and a most serious loss result. To retain this high fixed royalty is one of the most serious offenses against the conservation of petroleum.

A fourth method of using a sliding rate is the class method. Here the wells are classified at the beginning and a different rate used with each class. The classification is based upon the ratio of the value of the product to the cost of production. Normally some one variable factor in either of the items above would be the basis of the sliding. The one which will be most used and which the author recommends is the depth of the well.

To charge the same royalty rate for wells of 600 ft. as for those of 3,000 ft., has the effect of promoting "post-hole" drilling, as we call holes of inadequate depth. Such a wide distribution of shallow dry holes, where the untouched underlying strata are worthy of test, results not only in a direct waste, because the area must later be redrilled, but also in an indirect waste, because later operators, being in doubt as to the depth of the older holes, are afraid to risk drilling in territory thus improperly condemned. The classes should be few, and all wells in one pool should be in one or another of the classes.

For instance, if the one-sixth royalty charged in the eastern Osage Nation is extended to the western Osage, then the deeper sands of the western Osage would not be as systematically or economically prospected, as would be the case if the royalty was graded by depth of well. The author suggests one-sixth for oil in pools averaging less than 2,000 ft. deep, one-eighth from 2,000 to 3,000, and one-tenth below 3,000, for the present leases with their partly developed production.

Let it be remembered that the Mississippi lime (Boone chert) lies deeper than 3,000 ft. in much of the western Osage and that no test is thorough unless the drilling is continued until that formation is reached, when the upper horizons prove barren. Let no one suppose that because the Cushing and Boston pools have been great producers, all the deep pools of the Osage will be of that kind. West Virginia has plenty of deep small producers, and so has the Bartlesville sand. The system above outlined would encourage more thorough prospecting.

The objection that one-tenth and one-sixth are too great a difference will arise in the minds of those who think only of successful wells. It seems none too great when one remembers the amount of futile drilling which must be paid for by proceeds from wells that are successful.

The following are the requirements of a proper system of royalties:

1. It must be simple, so that it can be readily understood.
2. It must not be expensive or difficult to calculate.

It follows from these two considerations that it should have but few rates.

3. It must avoid uncertainties as to the time or point of changing rates.
4. Most important, it should permit the well to be pumped until its gross income has fallen to its maintenance cost.

To accomplish this last, the author suggests an exemption from royalty on the oil equal to the maintenance and interest on the junk. The slight loss to the land owner will be met ordinarily in the bonus, but sometimes by a higher royalty. For practical reasons the amount that should be exempted, instead of being exactly equal to the maintenance and interest on the junk, would be an approximate integral number of barrels, ordinarily one. When several wells discharge into one field tank, they may be averaged.

5. It should not encourage post-hole drilling, as opposed to thorough prospecting.
6. It should bear some relation to the cost of production.

For these two reasons we should, in addition, classify the royalty according to depth.

The objection which might be raised that the land owner would in some cases receive nothing for the use of the land during the last months of the history of the well, is met by the fact that he

has received advance payment for such use either in bonus or in large royalty during the early history of the well.

The application of the proposed method is shown in Fig. 145. In this case, with a decline of 15 per cent. and a royalty of one-eighth, which are not unusual, the life of the well was prolonged 9.6 months.

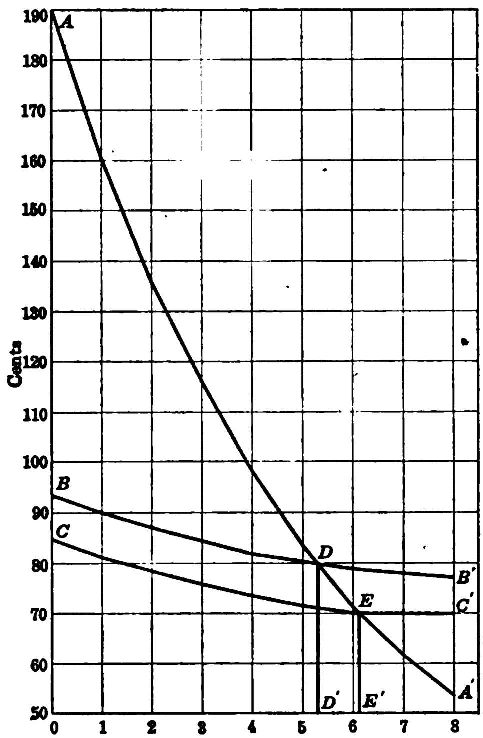


Fig. 145.—To show that a fixed exemption from royalty prolongs the life of a well. Price of oil, \$1.89. Maintenance, \$0.70 per well per day. Exemption from royalty of \$0.70 worth of oil per day.

A–A', Income from well; *B–B'*, maintenance and royalty without exemption; *C–C'*, maintenance and royalty with exemption; *D–D'*, time of abandonment without exemption; *E–E'*, time of abandonment with exemption; *D'–E'*, the prolongation of working life of well, 9.6 months.

Well Records.—The need of more accurate logs of wells has been reiterated by nearly every student of this subject. Indeed, inaccurate and inadequate logs, it must be said, are to be attributed much more to careless, indifferent and ignorant contractors and drillers than to any lack of appreciation of the part of superintendents and managers. However, the requisites of a good log include more than is usually appreciated, and, as time goes on,

more and more complete logs are sure to be demanded. A log should give an accurate steel tape-line measurement to the top, at least, of the most widely used key horizon in the field, and on the top of each producing sand. In addition, it should give the top of the water, if there is any, the bottom of the sand, and the bottom of the well. Other desirable items are a shallow reference horizon, a reference horizon as near as possible to the sand, and every sand yielding oil, gas, or water, and other limestones or red beds, unless very numerous, for the purpose of correlating the sands. These latter figures may be obtained by strings on the sand line, a method less accurate than the tape line, but so much cheaper as to be permissible for the less vital parts of the log. An improvement, within feasible limits, in logs alone would probably save us 5 per cent. of our dry holes.

Method of Locating.—All too many oil producers have settled down into a fatalistic habit of thinking that the success of tests is so uncertain that no care or skill is required in their location. This is a very costly blunder. While all experienced persons know full well the uncertainties of drilling, the demonstrable success of improved methods in locating wells is so manifest that a neglect of geological considerations bespeaks incompetence. No extended description is here possible, but the following brief outline may arouse interest for further study of these methods.

In locating test wells the age of the rocks should be favorable. Commercial gas has been produced as low as the Potsdam formation in the Cambrian period, and oil as low as the Trenton formation in the Ordovician period. There are no good theoretical reasons why both should not be found in commercial quantities lower in the Cambrian. Prospecting in the Pre-Cambrian is not to be encouraged, though occasionally, when the Pre-Cambrian is in some particular relation with other formations, it has derived oil or gas from them. It must be said that in America, however, the producer finds much more encouragement in the formations from Ordovician to Upper Pennsylvanian, and again from Upper Cretaceous through the Tertiary (Fig. 146).

The nature of the beds is of vastly more importance than their age. Ideal conditions are furnished by extensive dolomitization of limestone or beds of porous sandstone, 5 to 100 ft. in thickness, lying within shales twice or more as thick again. The shales should be gray, black, brown or greenish in color. White, yellow, red and purple shales are unpromising. Outcrops bearing

asphalt or ozokerite (mineral wax) are indicative of the presence of petroliferous beds, but by no means are infallibly safe indications of commercial deposits. Nor, on the other hand, does the lack of such evidence condemn a region. When drilling is not upon the crest of an anticline, dips of less than 5 per cent. are to be preferred, but are not necessary (Fig. 147).

The expected sandstones should be at a suitable depth at the selected point. An adequate cover wthout too much faulting is

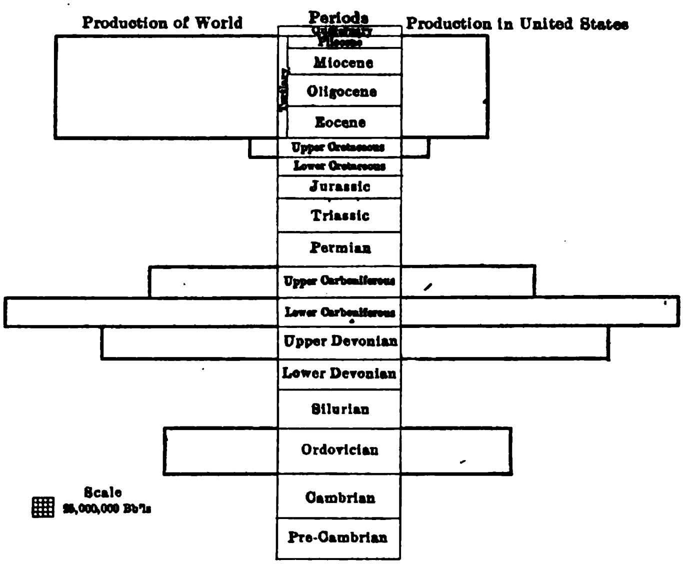


FIG. 146.—Stratigraphical distribution of petroleum production to 1913.

Tertiary	1,935,763,780 bbl.	California, Gulf Coast; foreign except Canada.
Upper Cretaceous	42,548,025 bbl.	Marion Co., Corsicana to Powell, Texas; Wyoming; Colorado.
Pennsylvanian	343,843,256 bbl.	Electra and Henrietta, Texas; Oklahoma; Kansas.
Mississippian	726,815,070 bbl.	Illinois; one-half of the Appalachian field.
Upper Devonian	540,304,235 bbl.	One-half of the Appalachian field
Devonian	14,099,053 bbl.	Canada.
Ordovician	318,095,570 bbl.	Lima-Indiana.

to be desired. This requires a greater thickness in the case of gas where high pressures are desirable, than with oil. Yet it is rarely wise to go to the very considerable expense of deep drilling when the expected sand lies below 3,600 ft. However, other exceptionally favorable circumstances might make it worth while, such as very promising geological conditions, high price of oil, or very large mounts of land owned or leased by the company.

Tests in new territory are best located at the highest points of well-marked domes. In the event of the dome being unsymmetrical in its dips, the well should be drilled a certain distance toward the lesser dips from the center, since the dome in the sand may not lie directly under the dome on the surface. This distance should be carefully computed according to Holland's method.[1] And next, where domes are not available, anticlines with level axes are to be preferred. Anticlines that plunge become proportionately less valuable.

When oil or gas has been discovered in one well, skill is necessary to locate adjacent wells, and also to choose and secure

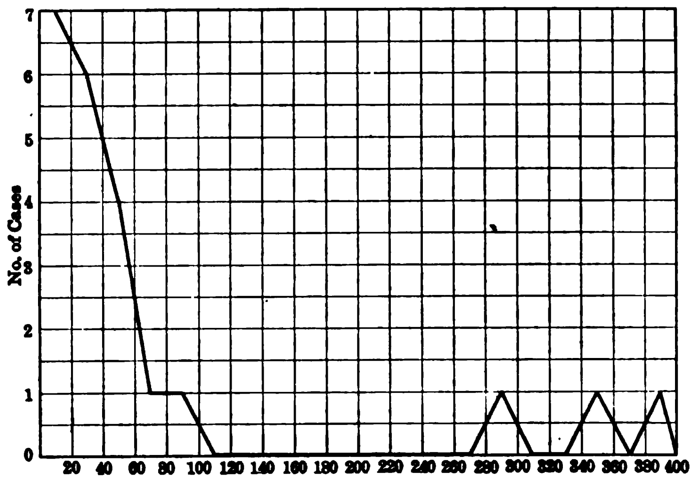


FIG. 147.—Graph of frequency of various dips in feet per mile. The pools were those in a district of southeast Ohio and northern West Virginia.

leases wisely, in order that there may be a minimum of dry holes and worthless leases. The producer may proceed according to several methods.

1. *Method of Strike.*—In this method new locations are made away from the discovery well in the two directions of the strike, that is, in such a direction that the sand is found at the corresponding level. This can be ascertained by learning the lay of the beds at the surface. From this data a map of some upper formation is prepared and, when enough holes have been drilled, the convergence or lack of parallelness between this upper bed and this sand can be mapped and allowed for. Then a map of

[1] *J. Inst. Pet. Tech.*, **1**, 15.

the particular oil-sand can be made. I. C. White[1] has been particularly instrumental in advancing this method.

2. *Method of Dip.*—In the event that a well has oil only in the lower part of the sand and gas in the top, when oil is sought for, the next well should be drilled down the dip, in order to reach the sand where the oil occupies a relatively greater thickness in the sand. Conversely, where the oil is found only in a few feet of the top of the sand and is underlain by water, the next well should be up the dip.

3. *Method of Streak.*—The oil reservoirs have neither uniform thickness nor great extent from side to side, except in rare instances. More frequently than not, the oil-sand extends farther in one direction than at right angles, making what is known to

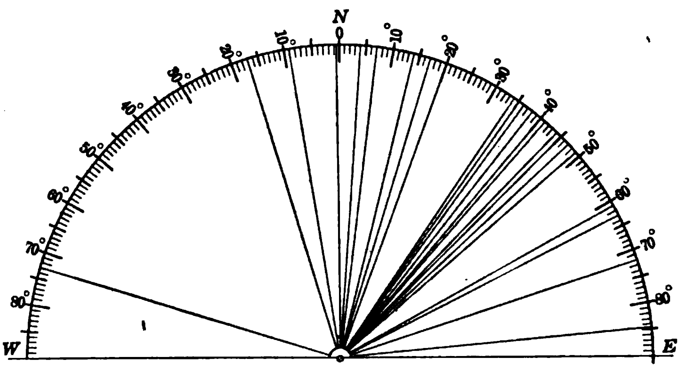


Fig. 148.—The direction of the long axis in the same pools, showing the origin of the common belief of N. 45° E. as the prevailing direction in this region and yet how variable it is.

the producer as a streak. In any one particular horizon, these streaks, though variable, generally have a prevailing direction. A comparison of near-by streaks in the same sand, or, if these are lacking, of other sands in the same field, offers some guidance. The producer should be alert to detect the thinning of the bed or reduced porosity in the several directions in order that the streak direction may be inferred as early as possible.

The method of streak is also valuable in connecting up two groups of wells, each centered around a successful test, but both in one streak. This possibility should always be kept in mind when the two groups are not separated by a distance exceeding the reasonable and common area of the reservoirs in

[1] *W. Va. Geol. Survey*, **1a.**

that sand. This is the more probable when the producing sand is at a corresponding depth below a reference horizon, and when the gas, oil, and water of the two groups are of similar quality.

The prevailing direction of the long axis of these sand bodies (or of the pool axes, if the data are not adequate for recognizing the former) is most easily expressed by means of polar coördinate paper, as in Fig. 148. The relative importance of streak and strike in determining the long axis of any field is well represented, after the strike has been determined, by plotting the angle, which the long axis of the pool makes with the strike, as in Fig. 149.

4. *Method of Inferred Shore Line.*—In fields where development has not gone far enough to determine the prevailing direction of the streak directly, an inference of some value may be

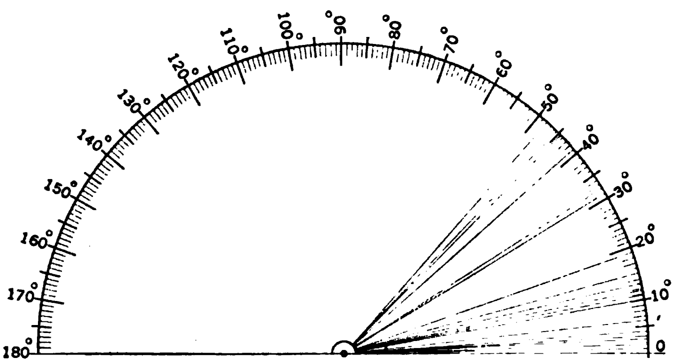


FIG. 149.—The deviation of the long axis from the strike in the same pools. Figures = degrees of angle.

based upon the probable shore line at the time of deposition. This requires the broad knowledge and experience of a geologist, who, in brief, would base his conclusions on the following principles. In general, the shore line lies at right angles to the direction of deepest water on the one hand, and of the dry land on the other. The direction of deepest water is indicated by increased thickness of purity of the limestones and the increased fineness of the material. The direction toward the continent is shown by increased coarseness of the material and the greater time interval represented by the unconformities. The present distribution of outcrops of different ages can also be used, but with great care, since subsequent movement and erosion of the beds introduce many complications.

5. *Method of Proximity.*—The rule of drilling next to good wells doubtless seems too axiomatic to be dignified as a method. Yet

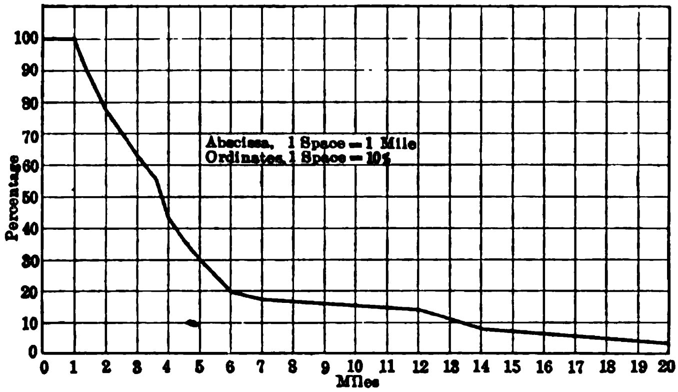


FIG. 150.—The percentage of the number of the same pools as long or longer than the distances indicated in the area studied.

one of the most important decisions a producer must make is that of leasing nearer to or farther from a discovery well of established production at correspondingly graded prices. It is therefore imperative that he estimate the relative values of different degrees of proximity. To do this, we take statistics of the dimensions of the known pools in that sand or in sands that seem most comparable. These should be plotted in a cumulative curve of frequency, separately as to the long axis (Fig. 150), short axis (Fig. 151), and for both axes of the pools (Fig. 152). From such curves the relative chance of a pool being of any particular size may be read. From these, after some allowance is made for the insurance of risk and after the value of the discovery well is computed, a proper price for leases at given distances from the discovery well can then be decided upon.

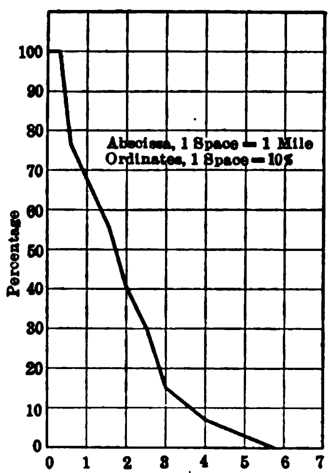


FIG. 151.—The percentage of the number of the same pools as broad or broader than the distance indicated in the area studied.

6. *Method of Pressure Decline.*—An unusual persistence of pressure after prolonged flow is of the highest value as indicating an undrilled extension of the reservoir.

7. *Method of Chemical Analysis.*—When the gas from a gas pool is relatively dry and light, considering its pressure, we may infer that that reservoir contains no oil, and save ourselves the expense of drilling further down the dip, so far as that sand is concerned. If, on the contrary, the gas is relatively heavy and oily in odor considering its pressure, we have strong indications, unless the sand is of extremely fine porosity, that prospecting down the dip does offer encouragement. It should be remem-

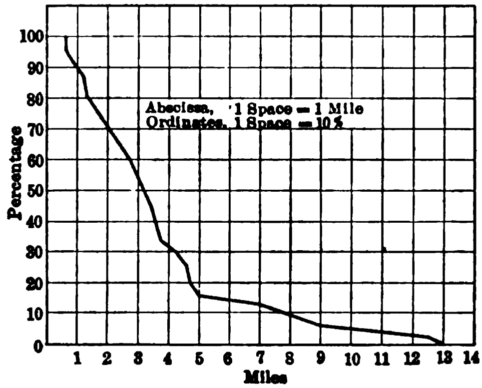


FIG. 152.—The percentage of the number of the same pools having an average diameter as great or greater than the distances indicated in the area studied.

bered that the very same pool will have its gas dryer and lighter in its earlier period when its pressure is high, than later when this is reduced. But when the gas is intermediate in quality, rather than markedly light or heavy, then a chemical analysis or compression test should be made. The results would guide the producer's further operations and also determine whether a gasoline extraction plant is advisable.[1]

The analysis of oil may be of use in making locations in the following circumstances: (1) To find if two pools some distance apart may be in the same sand, as, in that event, there would be a stronger chance of production in that sand in the intermediate territory. (2) To determine whether a given sand is the same as an outcropping sand showing oil, asphalt or ozokerite. (3) A

[1] See p. 437.

very heavy oil at a considerable depth causes a suspicion of a near-by fault or outcrop, whereas oil of extraordinary lightness has probably moved a long distance and has been subject to considerable fractional filtration. It is, therefore, less likely to be a successful commercial proposition, as in the recent strike at Calgary, Alberta. On the other hand, it is an indication of the general petroliferous character of the strata.

In the case of salt water, an analysis is also of value. The nature of the salts it contains assists in the correlation or non-correlation of the two sands in question. It may also help to determine whether the water pumped with the oil comes from the producing or some upper sand. But most important of all is the fact that methane and the next three members of the paraffin series are soluble in water to an extent of about 3 per cent., which varies, of course, with temperature and pressure. We may then analyze the water for a particular sand, and deduce from the content of methane and ethane the presence or absence of natural gas in the same sand farther up the dip. And if the analysis shows propane and butane, we should expect oil also in the same reservoir farther up the dip. If a test hole on the side of an untested anticline encounters water, we may by this method determine whether another test up the dip will be worth while.

Producers might wisely urge the Government to make a large number of comparative analyses to be used as standards of comparison, and further, that the various, possible analytic methods be compared with respect to their economy and efficiency for this class of work. In the meantime, however, we may employ current methods. Several companies are constantly making gas analyses, for the purpose of ascertaining whether the quality of the gas warrants the installation of a gasoline extraction plant. The method of sampling is of supreme importance in either case and should be done according to explicit directions.

8. *Geothermic Method.*—Höfer believes, and presents some evidence to substantiate his theory, that the increase of heat with depth is greater over oil deposits. The Carnegie Geophysical Laboratory is investigating along this line. But it must be said that the outlook for a successful use of this method is not very promising. It is difficult to see any connection between the isogeotherms and the presence of oil. It would appear theoretically reasonable to look for the association of gas with regions where the isogeotherms lie higher, since the greater heat may, as

indicated by the work of David White, have produced more gas. But nothing can be done in a practical way until the whole subject has been very much more thoroughly reported upon.

Spacing of Wells.—In the Oklahoma field half a million dollars has been spent on unnecessary wells in 2 square miles. Nearly any field shows most extraordinary waste from too close spacing. A marked contrast, as regards closeness of wells, may be observed where one company owns a very large tract and a group of small, competing leases hold adjoining properties. No general rule can be given as to the proper distance between either oil or gas wells. For each sand, the producers must watch closely the result of wells drilled later among the older wells. Since it is the common practice to lease in blocks or multiples of blocks of 10 acres, which equal 660 ft. square, it is wise to put oil wells at this distance of 660 ft. from each other, if this is approximately the distance that would have been selected for other reasons. There is a growing tendency to approach this distance among Mid-Continent and Illinois producers at the present time. In California, they still drill much closer than that ordinarily, because of the large size of the wells. And in the Appalachian field the leases are so irregular in shape that there is less incentive to conform to any particular distance.

Gas wells should be spaced at much greater distances, 1,320 ft. being sufficiently close.

When wells for either oil or gas are drilled on a very large tract of land, so that the offsetting of neighbors' wells is not a consideration, there is a more economical arrangement than the old one of locating the wells in straight lines crossing each other at right angles. By a staggered, or quincunx, arrangement, all of the given area may be brought within closer range of some one well, as is demonstrated by Fig. 153. This diagram also shows a common error when staggering is attempted. The distance between the rows should be shortened, so that the distance from a second row well to each adjoining first row well is the same as its distance to its neighboring second row well. Unfortunately, the staggered arrangement is seldom feasible on small leases held by competing producers.

On these small leases there is generally a well located in each corner. Between these corner wells, other wells are distributed at a distance from the property line equal to the distance at which the neighbor's wells stand back from the line. However, it is

by no means advisable to put in as many wells between the corners as the neighbor does. Very frequently a conference between two neighboring producers will lead to an agreement for each to omit a side well; for example, to omit a well between the two that may be already producing at the two ends of a lease 1,320 ft. long. Whereas, without such an agreement, one of the producers might drill in between, which would nearly always lead his neighbor to meet him with an offset, though it would be to the ultimate interest of both not to drill these accessory wells. The

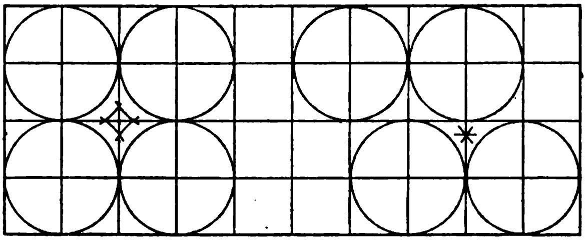


FIG. 153.—To show rectangular *vs.* staggered arrangement of wells. The area in the small square is farther from the wells than any point in the staggered arrangement.

same situation arises inevitably on all sides of a lease. A producer should always seek to enter into an agreement with each one of his neighbors, to the end that their wells may be as nearly 330 ft. back from the line and as nearly 660 ft. apart along their lines as each will consent to; this is, of course, if 660 ft. has been decided upon as the best distance for that particular sand and depth.

TABLE XL.—LOSS BY OMISSION OF OFFSETTING WELL

Along the long side of an 80-acre lease:	200 ft. from line Loss in acres	150 ft. from line Loss in acres
Case 1, 5 wells meeting 8 on the side of 4 tens	1.05	1.69
Case 2, 5 wells meeting 6 on the side of 2 forties	0.55	0.90
Case 3, 4 wells meeting 5 on the side of an eighty	1.01	1.88
Along the side of a forty:		
Case 4, 3 wells meeting 4 on the side of a forty	0.24	0.42
Case 5, 3 wells meeting 4 on the side of 2 tens	0.13	0.41
Case 6, 2 wells meeting 3 on the side of a forty	1.39	2.45

Table XL. gives the territory lost if one does not offset in the most familiar situations that arise.

The method of ascertaining the lost area is to draw lines on the map, each midway between a line well and each of its two opposing line wells, if one is not exactly opposite. This is done by drawing circles, with each well in question as a center, and joining the points of intersection with a line. These lines then make triangles, with the lease boundary showing areas lost or gained.

The area of the lost territory thus outlined must now be computed as well as any territory which may be gained from the neighbor. This may be done by making this construction on cross-section paper, counting the number of squares or fractions of squares included in the area. A more exact method is to compute the area of the triangle by the usual formula of the base times one-half the altitude. In the event that the area is polygonal instead of triangular, it is divided into triangles and the area of each computed and added together.

In unusually shaped leases, it is well to plan several methods of placing wells. If the cost of wells, the price of oil, and the royalty are fairly constant, it is quite possible to construct tables showing how much production to the acre the lease must have to warrant the drilling of a particular extra well. The tremendous loss occasioned by the cutting up of an oil or gas pool into many small holdings will be discussed later under the head of large versus small companies.

In fields where the dip is high and the sand coarse, such as is likely to be the case in some of the new fields to be developed in Alberta, it is better to have wells drilled closer along a lease boundary, paralleling the strike and less close to one paralleling the dip, as the interference of well with well is much less in the former case.

Depths to Which Wells should be Drilled.—This is an extremely important consideration, second only in importance to the selection of the location. And as regards depth, as in the case of locations, geological knowledge and skill are necessary. Quite commonly the tradition is established in a field that it does not pay to drill below a certain "farewell sand." In some instances this decision has been a wise one, but all too frequently it has been the result of ignorance of the formations below, and has resulted in the premature abandoning of thousands of wells. Before any test is drilled, the producer should investigate

the formations he is likely to meet, so as to have some idea of the depth. This advance knowledge is also useful to him in drawing up the drilling contract, and in deciding on the method of drilling and the size of the hole. A good illustration of the losses occasioned by loose work in this matter is that of the Cherokee Nation, where most of the early wells were stopped at the Bartlesville sand. Whereas, only 150 ft. deeper, more or less, depending upon the location, there is another sand distinctly worth while, and to which new tests now extend, and to which old wells, about to be abandoned, are being deepened. Another illustration, also in Oklahoma, is offered by the region from Owasso, to the Arkansas River, where it is quite probable that some producers have stopped wells at the Pitkin limestone, mistaking it for the Boone chert (Mississippi lime), which is not very much deeper and is yet worth drilling to. The Bridgeport, Illinois, pool is another instance where the early unsuccessful tests were almost all discontinued at too shallow a depth, often causing the surrender of leases that have since become productive. The most frequent cause of too shallow drilling is the indifference paid to the dip by drillers or producers who have come from older fields, where the dip is so slight as to be ignored by them. A well was unwittingly started at Boulder, Colorado, that could not have reached the producing sand till a depth had been reached more than twice that of the producing wells of the North Boulder pool. In most fields the geologist can predict the age and general nature of the strata to depths exceeding that feasible for drilling.

One should generally take care to drill through the whole of the oil-sand, for occasionally the shale which seems to underlie the sand may in reality be merely a break of a few feet of shale with additional pay beneath. Even though a lower pay is not obtained, this pocket is often valuable to receive sand and mud, which otherwise would accumulate in the hole and reach up to the level of the perforations and interfere with the pumping later.

However, in the event that the oil is found under very high pressure, the driller needs to be particularly careful in penetrating the sand, inasmuch as any underlying water will rush in the hole more readily than the oil and in some instances drown it out. In these cases of high pressure, it is best to let the well flow until

the pressure is reduced, when deepening can more safely be continued.

But where the contents of the pool are not under high pressure, because relieved by neighboring wells, there need be no such fear of water. It is desirable to drill through into the water sand, where the sand has a high porosity, since such a well, while pumping some water, also pumps an increased amount of oil. This happens because the removal of this water leaves a funnel-shaped depression in the top of the water sand and in the bottom of the oil-sand, which induces a more ready flow of oil into the hole, both by means of the gradient established and by contact of the oil with the less viscous and more easily flowing water. This method of purposeful deepening of oil wells into the water sands is patented in the United States,[1] but not in Canada.

Neglect of Shallow Sands.—We have in the history of many fields a later development of a shallow sand that was passed through by early operators, being considered too insignificant for production, or because gas only was sought at the time. There have been many instances in Oklahoma where oil has oozed slowly from some shallow sand around the casing to the surface. Such a sand has, in nearly every instance, later proved worth while when properly shot. It is remarkable how shooting has made sands productive, which at first seemed disappointing.

Unless absolutely necessary, the operator should avoid drilling test holes by the rotary method, as in that case he gets poorer logs, and may pass through a very fair oil-sand without detecting it, because of the weight of the considerable quantity of mud and water which holds back the oil and gas.

Pumping.—The best results in pumping, after the pressure has declined, is obtained by frequent, intermittent pumping rather than by prolonged, occasional pumping. In wells of reduced pressure and very porous sand, one of the principal factors in bringing the oil into the hole is gravitational seepage, and, of course, this cannot be effective when the oil stands high in the hole. Devices for automatic pumping, controlled by the accumulation of the fluid, have not as yet been successful. An automatic periodic, mechanical, turning on and shutting off of power would be quite feasible, if the pumping were by electricity or compressed air, steam or gas engine powers, equipped with self-starters. Producers should appreciate the great economy of

[1] United States Patent 1083018.

pumping several wells by one power. All too frequently the installation of multiple powers is too long delayed. We can anticipate, with the improvements time will bring, improved powers that will not only pump a larger number of wells, but will also pump from greater depths.

More Efficient "Extraction."—It is customary at the present time to continue pumping in the usual way, till the receipts have fallen below the maintenance charges. Then the well is abandoned without any additional efforts to get the last of the oil. If we calculate the amount of oil per acre from the porosity of the sand, we find that the amount actually "extracted" is considerably less than 50 per cent. in the case of firm sandstones, and even in the loosest sands is seldom more than this. In the aggregate this loss is staggering. The time has come when we should make a determined effort to obtain the "unextracted" oil.

The first step in this direction is doubtless a more careful conservation of well pressure, as it is this which is especially effective in driving the oil to the hole. To this end, it is advisable to equip all drilling holes where high pressure is expected with control casing heads. By this means a sudden strike of oil or a prolonged flow after a shot may be piped into the tank, without that occasionally long and useless gushing over the derrick.

The method of handling new wells is greatly affected by the rate at which the neighboring wells are calling upon the pressure and dissipating it. The following procedure would require modification if the neighboring wells were dissipating pressure faster than is here assumed.

It is desirable to tube a flowing well early with the perforations set low in the sand, for this does not seriously reduce the production, and it has the merit of keeping the pressure of the gas in the upper part of the sand in place, where it is valuable for its power of expulsion. But there is a small hole in the working barrel at the top of the sand to keep the top of the oil high and so not expose the sand face as long as the pressure is such that the oil is forced into the hole up to a point far above the top of the sand. From the gas trap the line should go to a covered tank. This, if other circumstances, such as aridity, favor its use, should be of iron instead of wood, for the greater tightness. The vapor from the top of such tanks, as well as that from the gas trap, should be piped to a gasoline extraction plant.

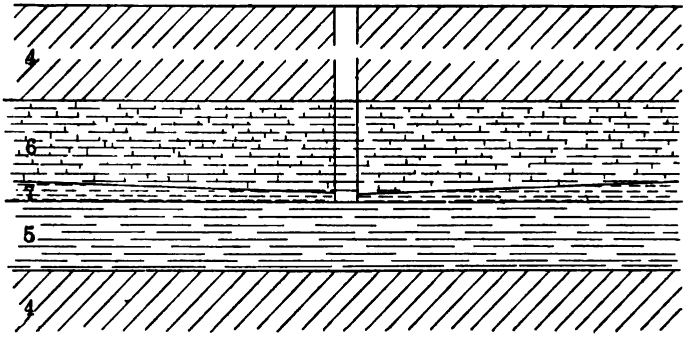
Miles W. Quick contends that the casing head should be

periodically closed and opened at this stage, so as to save pressure and yet obtain a pressure gradient forcing oil into the hole, and at the same time to warm the sand face so as to prevent the clogging effect of refrigeration, caused by the expansion of the oil and gas as it enters the hole. Care should be taken not to pump after the oil has been pumped out down to the perforations. When production has greatly dwindled, and the pressure is found to be low, the regular perforations should be a little below the bottom of the sand, and the working barrel should have no perforation. But if there is water, then the perforations should be placed only partly below the level of the water. From this time on, pumping should be at frequent intervals, so as to keep the level of the fluid low. This may increase the paraffin deposit on the sand face; but it is necessary to get the full effect of gravitational seepage, and the paraffin will be very much less than it would have been earlier, when the pressure was high. The casing head can now be pulled upon regularly by the gasoline extraction plant, only slightly at first, then gradually more and more, till as high a vacuum is attained as is feasible. In Smith and Dunn's method, the pressure gradient is further sustained by a like device of introducing compressed air into some abandoned wells. Then, in turn, this method will also be abandoned as too unproductive.

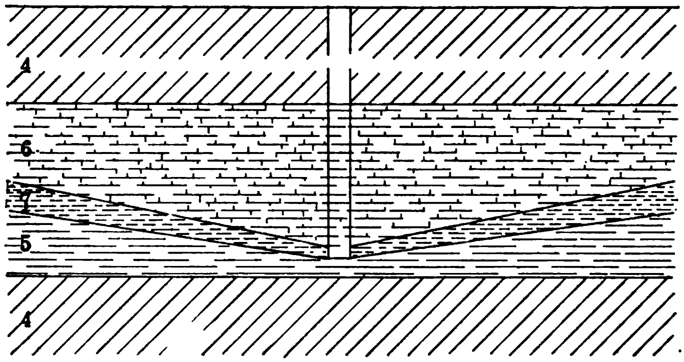
There will ordinarily be little trouble from paraffin with the procedure above described, until the perforations have been set low. After this, when the production is considerably reduced, it is sometimes desirable, after as much cleaning as is necessary, to treat the sand face with an electric well-heater for 100 hr. In case the producing company refines its own product, it would be advisable to follow the heating with a naphtha bath or the naphtha bath may replace the heating.

When production has reached an unprofitable point, the well should not be abandoned, but held in reserve until the whole pool can be brought under the management of one great company or of several cooperating companies. Only by concerted action can the next effort by the water-flush method be used to extract the remaining oil. Water should be turned down the well situated at the lowest point of the sand. It can be obtained either from one of the shallow sands or else introduced from the surface. This should be run in fast enough to keep the hole filled up to the source of the water, in order to have a good head and correspond-

ingly rapid penetration. Then an adjacent well should be given test pumpings, if not regularly pumped, until the on-flow of this water increases its oil output of the second well. After a period of much improved oil production, it will yield more and more water in ever-increasing proportions. Then when the amount



Showing the accumulation of the oil in the lower part of the sand as it becomes drained. The oil becomes dependent upon gravitation for movement to the well. As it flattens out, the gradient becomes less and the movement declines. 4, shale; 5, water; 6, drained sand; 7, oil.



Showing the effect of deepening the well into the water sand, and so causing a flow of water to the well and a funnel-shaped depression in the water surface, which increases the flow of oil to the hole.

FIG. 154.

of oil is no longer in paying quantities, this well in turn, where feasible, should serve as a point of entrance for water. In this way, the oil is gradually flushed up the pool to the highest wells. When only these highest are producing, discontinue introducing water at the lowest wells, so as to prevent the oil being washed by the water up to the dip past these wells. Theo-

retically, it would seem wise to keep the wells farther down the dip open, so that compressed air could be forced in. This air, bubbling through the water-filled sand, ought to disengage some oil that the moving water alone could not dislodge. The accumulation of the air in little domes and pockets in the top of the sand would dislodge oil that had been retained there, so that it would move on up the dip to the pumping wells. Whether this compressed air system will warrant the expense, only actual trial can prove. But judging from the outcome of laboratory experiments, the prospect is promising.

Where one company controls a pool, the percentage of oil extracted will be greatly increased, if gas wells in the same porous reservoir are not used until the oil is nearly exhausted. The ideal would be to have oil taken from wells in the lower part of the pool where the upper part of the sand does not contain gas. Production from such wells only would show an unusually gradual decline curve, for it is obvious that in this way the pressure loss is slightest for a given production. The difference would be less if the sand was very "close."

The rapid falling off of pressure in the north Cushing field is very disappointing to the operators in that pool. If the full significance of the loss in increasing the percentage of unextractable oil were fully appreciated by them, it would be taken still more seriously. Much of this loss of pressure was the result of escaping gas. The difficulties as well as the importance of such wastes are well known to operators, and the waste took place because they did not think they could afford to take any other course. But there was one notable exception—the burning well in the Cimarron River bottom. This the owners of the well, as well as all operators in the pool, were very eager to control; but control was not accomplished for days, during which the well was losing from 35,000,000 to 60,000,000 cu. ft. of gas daily.

But, in addition to these fires, we have the drilling in of big "gassers" near oil territory and in the same sand, or in the upper part of the sand above the oil, which "get away" from the driller. A bad blow-out may result or the well may catch on fire. Only feeble efforts are made to control it, because the operator does not know how. In any event, a long delay is occasioned by incompetent methods or waiting for materials. Such wells are frequently "wildcat" and the operator cannot

afford to spend much money in expensive preparations to shut in a bad blow-out or burning well, such as have occurred at Caney, Kansas, at Oil Springs in the Caddo field in Louisiana, or in the Cimarron River bottom at Cushing. Other operators look upon it as a personal affair, without realizing that every day that such a gas well burns or blows means just so many more barrels of oil which can never be recovered from their own wells, and brings so much nearer by months the time such oil wells will have to go on the pump, and also the time when they must be abandoned.

The fact is well known that such wells, drilled in the early history of a pool and allowed to blow, very considerably reduce the gas pressure in that pool—it may be as much as 100 to 200 lbs. Now, gas pressure in most pools is by far the biggest factor in the expulsion of oil from the sand. In other words, if the gas pressure is very low—say 25 lbs. or less—no oil in paying quantities could be produced from any well whose sand has less than a certain degree of fineness, without the aid of gas pumps or other unusual aids, or unusual natural conditions, such as encroaching water.

At Hamilton Switch, where the gas waste was notorious, the pressure in the wells dropped probably more than a pound per day for some time. The effect of this was immediately shown in the production curves of the wells in this pool, which declined very rapidly. Proportionately less of the oil content of the sand of Hamilton Switch was recovered than if this waste had not been permitted. If a fire consumed the amount of oil which was lost in that pool by failure to recover it from the sand, the catastrophe would have been startling.

Control of Wild Wells.—While we may expect a reduction in the number of wild wells, through the introduction of control casing heads, some other means than reliance on the individual producer must be found. It is well known that in the mining industry the United States Bureau of Mines has assumed as one of its functions the establishment and maintenance of rescue cars, which are at the call of any mine where an accident creates an imperative need for efficient organization and adequate equipment in coping with just that sort of emergency. It would be very difficult for a group of operators in the oil business to maintain such an equipment and organiza-

tion, although it is to the general interest that such wild wells be immediately capped.

When not only the possibility of such losses is considered, but the fact that they are occurring every year, would it not be a great additional service which the Bureau of Mines might render to the petroleum industry in maintaining two cars located at strategic points—as Bakersfield, Cal., and Tulsa, Okla.—equipped with the most approved fire-fighting apparatus and other paraphernalia for controlling wild wells, and in charge of an expert in this kind of work? The Bureau already has such men in its service. Between times they could be engaged in their present work near these points, but would be at the call of any wild or burning well. The experience thus gained would lead to improvements in methods and equipment, so that such work would soon be much more expeditiously accomplished.

Two objections might be raised.[1] First, that it is better to educate the operator to prevent blow-outs and fires. By all means educate as far as possible. But let no one suppose that this will end blow-outs and fires. Where the chances of disaster are very small, men will never take precautions that are irksome or expensive. But it is these very small chances which lead to serious disasters.

The second objection is that the Government should not assume the expense in this way, since some individual was at fault. However, the benefit is so much greater to the other operators and land owners than to the operator in question, that they cannot afford to leave the decision in his hands. Further, the control is frequently so expensive to him as to be ruinous. A close parallel can be found in the case of the fire departments of cities. Because a fire threatens more than the one house which is burning, the community finds it to its advantage to accomplish the extinguishing in the quickest and most efficient way, even though the Government incidentally pays for it.

We need an emergency car, then. Congress should provide an additional appropriation to the Bureau of Mines, and thus minimize the damage to the Nation's store of oil and gas from these recurrent disasters.

Size and Scope of Companies.—The relative efficiency of large and small producing companies is a matter of great interest

[1] See Johnson and Huntley, "Plans for the Control of Wild Gas Wells," *Oil and Gas Journal*, May 6, 1915, 26.

and importance. The following theoretical considerations, as well as actual practice, all point to the *advantage* of large units of capital and management. The advantages are:

1. Ability to employ more efficient and more highly specialized men, and give a wider application to their activities.

2. The reduction in the number of offsets to be drilled.

3. Ability to connect up the largest number of wells that each power is capable of pumping.

4. Economy in labor, by having one pumper tend several neighboring powers.

5. The more continuous utilization of the plant and equipment, such as pulling machines, for instance.

6. Saving in time and teaming by maintaining well distributed and stocked storehouses.

7. The ability to install a gasoline extraction plant, because of the company's control of the necessary number of neighboring wells.

8. The conservation of pressure and the use of water-flushing can be more frequently employed when the whole pool is owned by one company, or, at most, by but a few companies whose managers could easily reach an agreement, which would be difficult were there, instead, many small lease holders.

9. Important experiments can be tried, such as testing the relative merits of competing methods and materials.

10. Economy of surveying.

11. By holding several contiguous leases, instead of a few scattered ones, a large company may "feel out," from established production, location by location, relatively unhampered by property lines.

12. By holding several contiguous leases, the large company will far less frequently be forced to drill according to the terms of the lease, before the needed information is in hand.

13. The logs in a large company are nearly always more carefully recorded and are always available. Whereas, among many small companies, there are invariably some who keep very poor logs or hold them secret, and in some cases there are some who even falsify their records. By means of this fuller information, casing requirements and the proper depths of tests can be anticipated, sometimes saving an unnecessary hole, or preventing the premature discontinuance of a well.

14. Lower prices, better quality and greater uniformity in supplies are possible when purchased in large lots.

15. The economy of a large company drilling its own wells without letting them out to contractors. Or, if because of the difficulty of getting a competent superintendent of drilling, the company decides to contract, this can be done at far cheaper rates than ordinarily, from the circumstance of there being many wells close together in one contract.

16. A lessened danger from premature flooding by water from improper casing or plugging. Also, less gas waste by small, irresponsible or incompetent neighbors.

These foregoing reasons apply to the greater efficiency of concentrated or large producing companies. The following considerations indicate the higher efficiency which results from the integration of the industry, that is, the bringing under one management of the various successive steps in the oil and gas industry, such as production, transportation, refining, and distribution.

1. With integration, it would be possible to store oil in relatively few central, large, steel tanks, when otherwise the oil would deteriorate more rapidly in numerous small and more leaky tanks.
2. Gasoline extraction plants can extract gasoline from the storage tank vapors, since there would be enough to make it feasible.
3. By controlling, to a certain degree, the rate at which wells are drilled, the danger of overproduction may be reduced and a steadier market assured.
4. The oil and gas business should be in the hands of the same company, as otherwise the one-sided eagerness of the oil producer may lead him to waste vast quantities of gas. The search for gas is made easier by the knowledge obtained in the oil operations and *vice versa*.
5. Pipe lines and laterals can be planned in a more systematic and farsighted way.
6. Water and fuel for pumping and drilling can more frequently be supplied from the nearest available source.
7. The guarantee of a regular production for the refinery makes for greater economy and efficiency there, as well as in the marketing of the oil.

As a partial offset to these advantages of both concentration and integration, there are the following five foes to efficiency in all large scale business:

1. Unwarranted favoritism in appointments and promotion. However, there is much more of this evil in small companies than is usually supposed.
2. Slacking up, because the personal interest is less keen and vital.
3. The temptation to sacrifice the interests of the company to those of officers, superintendents and foremen.
4. Jealousy among departments or divisions of the company.
5. A clique spirit that tends to advance the men already with the company, when sometimes new and valuable men from the outside are needed.

These difficulties are not necessary, and can be overcome, in a large measure, by a high degree of executive ability on the part of the higher offices. In practice, the losses from these five causes are evidently less than the gains in most cases, because, as a matter of fact, the large, integrated companies are constantly buying more properties, so that the percentage of leases held by the great companies is steadily increasing.

The greatest losses of efficiency result from dividing the operations in one pool among several companies. This condition can only rarely be remedied in the old pools or where the surface area is cut up among holders. On the public lands, though, which are to produce so much of the oil of the United States, the decision lies with the Government. To overcome the difficulties and accomplish unified management, the Oliver plan has been proposed.[1] In this the Government takes a large area of the public land, making a natural unit (which has been reported by the United States Geological Survey as probably productive), and leases it to one company made up for the purpose. The Government asks for subscriptions to stock in this company, and the amount held by each subscriber is limited. Only by this method can the desirable end—of one pool operated by one company—be accomplished.

Wiser Utilization of Oil.—Once the petroleum is pumped to the surface, there is very little preventable loss, other than that in casing-head gas[2] and by evaporation. Yet there is one very serious loss of a different and wilful type—the burning of good oil for inferior uses. For instance, it is common to burn a grade of oil under the boilers that is capable of being refined into lubricating oil, and which may even carry a fair percentage of gasoline, kerosene, and paraffin. Doubtless where coal is scarce and oil inferior and plentiful, this is justifiable. To burn the residuum of most oils elsewhere, except for specific purposes, would be a lamentable use to make a product that would be worth so much more in the future for higher purposes. Moreover, when an oil is to be used for the production of power, far greater efficiency can be had by the internal combustion engine, of either the carburetor or Diesel type, than by burning it under a boiler.

[1] See *Senate Hearing on H. R. 16136, 63rd Cong., 3d Session.*

[2] See p. 438.

CHAPTER XI

THE CONDENSATION OF GASOLINE FROM NATURAL GAS[1]

The occurrence of gasoline in gas pipe lines, noted long ago, probably first brought to mind the possibility of extracting gasoline from natural gas, but it required the increased demand for gasoline of recent years to make its production in this way a matter of commercial consequence.

A. Fasenmeyer made gasoline from the gas of oil wells near Titusville, Pa., in the fall of 1904. His plant is almost within sight of the old Drake well. His first equipment was a makeshift affair. The gas from the wells, after leaving the gas pumps, was cooled by passing through a coil of pipe immersed in a tank of water. The condensate produced was allowed to drip into a wooden barrel and the losses resulting from evaporation were large. The product when first collected had a gravity of 80° to 90°Bé. Fasenmeyer's production the first year was approximately 4,000 gal., for which he received 10 cts. per gallon. Tompsett Bros., of Tidioute, Pa., claim to have preceded Fasenmeyer in the operation of plant on a commercial scale, and they are operating successfully at the present time.

As these ventures proved a commercial success, attention was turned to the designing of better plant equipment.[2] Gas and oil operators in other oil fields in the United States proceeded to install gasoline plants.

[1] Based upon *Bulletin* **88** of the *United States Bureau of Mines*, **1915**, to which the reader is referred for detailed information. See also *Technical Paper* **10** of the *Bureau of Mines*, **1912**; and SINGER's comprehensive report on the manufacture of natural gas condensates in *Petroleum*, **9** (1914), 453–75. SINGER gives an extensive bibliography.

For G. M. SAYBOLT's absorption method, see United States Patent 989927, April 18, **1911**. The Saybolt process, which is owned by the Standard Oil Company, is now used by the Hope Natural Gas Company. of Pittsburgh, Pa. Natural gas is caused to bubble, at a suitable pressure above atmospheric pressure, through a medium (oil of sp. gr. 0.85 to 0.90) capable of absorbing naphtha. On absorption methods, see BURRELL, BIDDISON and OBERFELL, *Met. Chem. Eng.*, **14** (1916), 651.

[2] On the patented processes for making casing-head gasoline, see CHUTE, *Met. Chem. Eng.*,**12** (1914), 147.

Growth of Industry.—The making of gasoline from natural gas increased from a production of a few thousand gallons in 1904 to about 43,000,000 gal. in 1914. Not until 1909 did the industry assume commercial importance. According to the United States Geological Survey, the increase in production of gasoline for the year 1912 over 1911 was 63 per cent.[1] The rate of increase for the year 1913 over 1912 was 100 per cent. The gas used represents that which previous to the installation of plants for the production of gasoline was principally wasted, being, for the most part, "wet" gas which comes from the casing heads of oil wells.

Constituents of Natural Gas—Natural gases are mixtures in which the hydrocarbons of the paraffin series predominate, and methane is the preponderating constituent, the characteristic hydrocarbon of all natural gases. Small quantities of nitrogen, carbon dioxide, and water vapor constitute the impurities. In some gases, however, the percentages of nitrogen and carbon dioxide are large. One analysis has been published in which nitrogen comprised 98.5 per cent. of the total, and another in which the carbon dioxide equaled about 30 per cent. of the total.

The exact proportions of the constituents in natural gases cannot be determined by ordinary methods of analysis, although the total quantity of paraffin hydrocarbons can be thus obtained and the heating value and specific gravity determined. Natural gas may be separated into its constituents by liquefying it by means of liquid air and separating the constituents of the liquefied gas by fractional distillation. By this means Burrell, Seibert and Oberfell[2] showed that the natural gas used in Pittsburgh contained 84.7 per cent. methane, and that an extremely "wet" gas from which gasoline is condensed commercially contained only 36.8 per cent. methane.

The paraffin hydrocarbons that principally concern the gasoline producer are methane, ethane, propane, and the butanes, pentanes, hexanes, and heptanes. Of these, the first four are gases at ordinary temperatures, the last three liquids. The gases after contact with the oil in the earth bring with them the vapors of the liquid hydrocarbons. The vapors are carried along with the permanent gases in the same manner that water

[1] On the production and technology of the natural-gas gasoline industry in 1912, see *Oil, Paint and Drug Rept.*, **85** (1914), No. 13, p. 33.

[2] *Bull.* **88** of the *United States Bureau of Mines.*

TABLE XLI.—ANALYSES OF NATURAL GASES FROM VARIOUS FIELDS[1]

	Constituents								Remarks	Analyst
	Methane	Carbon monoxide	Carbon dioxide	Nitrogen	Oxygen	Hydrogen	Other hydrocarbons	Other constituents		
California—Fresno County, Coalinga Field	88.00		11.10	0.90					Collected by G. H. Salisbury, June 10, 1910.	G. A. Burrell.
King County, Sunset Field	87.70		10.50	1.80					Collected by I. C. Allen, July 16, 1909.	G. A. Burrell.
Los Angeles County, West Los Angeles	91.00		1.00	5.20	0.10		2.70		Collected by I. C. Allen, July 23, 1909.	G. A. Burrell.
Santa Barbara Co., Santa Maria Field	62.70		15.50	1.40	0.20		20.20		Collected by I. C. Allen, Aug. 5, 1909.	G. A. Burrell.
Kansas—Allen County, Iola	94.50			5.08	0.23			H-trace He-0.18	Collected June 10, 1906	Hamilton P. Cady and David F. McFarland.
Chase County, Elmdale	78.60		0.15	12.13	0.30		8.26	He-0.56	Depth, 152 ft.; pressure, 45 lb.; collected Oct. 6, 1906.	Hamilton P. Cady and David F. McFarland.
Louisiana—Caddo field	95.00		2.34	2.56				0.01		F. C. Phillips.
New York—Chautauqua Co., Fredonia	90.05		0.41	9.54						F. C. Phillips.
Pennsylvania—McKean County, Kane	90.38		0.21	9.41	Tr.					F. C. Phillips.
Washington County, Houston	84.26		0.44	15.30	Tr.				Contains also trace of ammonia.	F. C. Phillips.
Westmoreland Co., Murrysville	97.70		0.28	2.02	Tr.					F. C. Phillips.
West Virginia—Marion County, Fairmont	81.60	0.40	0.10	3.21	0.20	0.20	14.29			C. C. Howard.
Austria—Wels	97.10		1.30	1.00	0.60				Specific gravity (air = 1), 0.5667.	
Germany—Neuengamme near Hamburg	91.50		0.30	4.60	1.50		2.10			
Hungary	92.05		0.65	7.30						
Russia—Samara	53.35		1.17	40.86	4.22		0.40			
Daghestan	65.84		12.82					Ethane, 19.92		
Tchelcken	77.30	3.50	3.60	8.90	1.80			Olefines, 4.80		
Caspian Region	93.07		2.18	0.49		0.98		Olefines, 3.26		
Baku (Peninsula of Apscheron)	92.89		0.93	2.13		0.34		Olefines, 4.11		
England—Staffordshire, Charlemont	99.60		0.30	0.10						
Sussex, Heathfield	93.16	1.00		2.90				Ethane, 2.94		

[1] For additional analyses, see Clarke's "Data of Geochemistry," *Bull.* **616**, *U. S. Geol. Survey*, 715; and *Bull.* **88** of the *Bureau of Mines*, 21 and 22. For a comparison of the composition of natural gases throughout the world, see NIEDERSTADT, *Z. öffent. Chem.*, **20** (1914), 386. On the occurrence of natural gas, see Hager, *Eng. Min. J.*, **100** (1915), 959.

vapor exists with air. After treatment in the gasoline plant, where the capacity of the gases to carry the vapors is much lessened, the vapors are deposited.

Factors Affecting Yield of Gasoline from Natural Gas.[1]—The quantity of gasoline vapors in any particular gas mixture is dependent upon the character of the oil in the sand, the temperature and pressure existing in the sands, the porosity or closeness of the strata, the intimateness of contact between gas and oil, and other less important factors. The pentanes, hexanes, and heptanes are the only constituents of crude oil that, at earth temperatures, have vapor pressures of such magnitude that they are distilled in quantity from the crude oil; hence, they are the chief liquid constituents of natural-gas gasoline.

In wells yielding gas suitable for gasoline condensation, the three gases, methane, ethane, and propane, invariably occur in the gaseous condition, and butane also is usually present in the gaseous condition.

Methods of Testing for Gasoline Yield.—By itself the ordinary eudiometric analysis is of little use for testing a sample of natural gas in order to determine its suitability for gasoline production. Laboratory methods in principal use have to do with solubility and specific gravity tests. The Bureau of Mines has used alcohol and claroline oil; 100 c.c. of the gas is shaken with 35 c.c. of the oil or with 50 c.c. of the alcohol until absorption ceases. For the determination of specific gravity Burrell and his co-workers have both weighed the gas and used Bunsen's effusion method. These investigators have found that natural gases at present used for gasoline production have a specific gravity of 0.80 or higher, and are soluble to the extent of 30 per cent. or more in the solvents used. Laboratory tests serve best as preliminary indications previous to tests of the gas at the well by means of an experimental compressing plant.

Use of Pitot Tube and Gas-Analysis Apparatus.—The Pitot tube as ordinarily used for measuring the flow of gases, that is, where the static pressure is not obtained, may give results that are 8 per cent. in error, even though the tube is correctly used. When the static pressure is obtained and all readings are taken with a sufficient degree of refinement, they may vary only 1 per

[1] Burrell, Seibert and Oberfell, *loc. cit.* It may be noted that by absorption methods much of the so-called "dry" natural gas can be treated.

cent. more or less from the correct results. The amount of casing-head gas that flows from a casing head may vary from little or nothing up to 500,000 or more cu. ft. of gas per 24 hr. Wells should be allowed to vent from 3 to 24 hr. before measurements of the flow are made.

A simple gas-analysis determination will show an operator whether air is leaking into his gas mains. Some gases that are used for condensing gasoline contain 40 per cent. or more of air, due to leakage.

Life of Wells as Regards Gasoline Production.—Regarding the life of wells as to flow of gas for gasoline condensation, it can be stated that wells from which gas has been escaping freely for several years will be long enough lived to insure a return of the initial investment with profit, that is, if the gas contains the necessary quantity of gasoline vapors.

Data Regarding Compression.—The condensation of gasoline from natural gas is a physical process. The process in principal use at the present time consists essentially in compressing the gas to pressures up to 300 lb. and cooling it with water of ordinary temperature (see Fig. 155). Cooling the gas by means of a refrigerant without compression, or using a refrigerant other than water in conjunction with compressors, are processes that are also employed.[1]

The pressure best suited for the condensation of gasoline from natural gas depends upon the partial pressures of the gases and vapors present in the mixture. The partial pressures are difficult to determine. Hence the best that one can do in plant operation is to experiment until the most suitable pressures are found.

Single-stage or two-stage compressors are generally used in gasoline-plant operations. Single-stage compressors are used where pressures of 110 lb. per square inch are not exceeded.

Several changes occur in the gas when it is treated in a gasoline plant for the condensation of gasoline. One has to do with the condensation of vapor, another with the liquefaction of gas, and a third with the solubility of gases in the liquids produced.

The condensate as it is received in the accumulator tanks consists principally of the liquids pentane and hexane and the lique-

[1] See LANEY, *Bessemer Monthly*, December, **1913**, 1. Absorption methods have been used for many years in Germany and to a large extent during 1915 and 1916 in the United States.

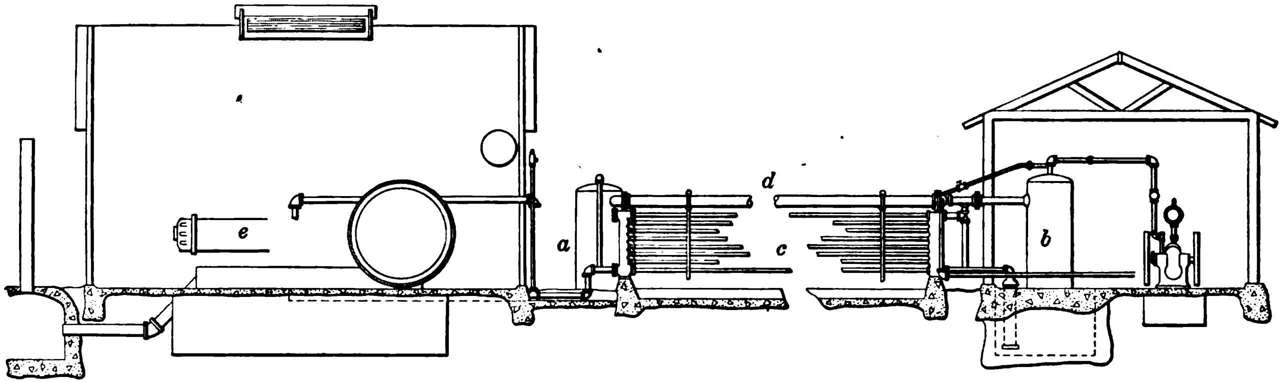


FIG. 155.—The elevation of a compression type of plant for making gasoline from natural gas.

The gas from the wells enters the plant by means of a gas line. After passing through a drip tank *a*, for the removal of oil that might be carried with the gas, it enters the low-stage compressor; after compression it is forced through the low-stage cooling coils, which are generally cooled by water, and thence to the high-stage compressor *e*. From this it passes to the cooling coils *c*, which are showered by water, from which it is expanded through a suitable valve into the jacketed pipe *d*, where it produces regenerative cooling. The condensate is trapped into the accumulator tank *b*, and the residual gas may again be passed back into the compressors through a conducting line. However, the more recent and seemingly better practice is, instead of expanding the "stripped" gas through a valve by which it produces a slight regenerative cooling effect, it is expanded by being made to do work against a moving piston which makes a much larger reduction in temperature, thus markedly increasing the efficiency of regenerative cooling. At the same time work so produced may be utilized in pumping the condensate, compressing, returning gas to the field, etc.

fied gas bütane. Some heptane and liquid propane may also be present.

For a particular natural gas there is a certain pressure best suited to produce the most salable gasoline. Increasing the pressure may result in producing more condensate in the accumulator tanks, but the additional yield may be so volatile as to quickly escape after exposure to air.

The quantity of gas that dissolves in the condensate in the accumulator tank is so small as to be insignificant.

At least one plant in the United States using a refrigerative method with low pressures is in successful operation.

Cost Data.—Exclusive of foundations and housing for machinery, pipe lines to wells, railroad sidings, storage tanks, etc., the compression and condensing equipment for gasoline plants costs from about $2,800 for a plant for handling 120,000 cu. ft. of gas up to $7,800 for a plant for handling 600,000 to 700,000 cu. ft. of gas. Two plants that produced 490,000 gal. of gasoline in 1913 cost $40,000 to complete. The owners realized 55 per cent. on their investment the first year.

Heating Values and Explosive Limits of Natural Gases.—The heating value of the natural gas used for the condensation of gasoline from natural gas may be as high as 2,500 B.t.u. at 0°C. and 760 mm. pressure. None of the residual gases tested by the Bureau of Mines had a heating value lower than 1,000 B.t.u. At one plant the residual gas had a heating value of almost 2,300 B.t.u.

The explosive limits of the natural gases used for the condensation of gasoline from natural gas are low and narrow. These limits are approximately, for the low limit, 3.5 per cent. gas, and for the high limit, 9.5 per cent. gas.

Special precautions must be taken to avoid explosions.

Evaporation Losses.—Evaporation losses that resulted when natural-gas condensates of different specific gravities were exposed to the atmosphere in certain forms of containers ranged at one plant from 4.5 per cent. to 24 per cent. at the end of the first hour, from 8.5 to 33 per cent. at the end of the second hour, from 9.5 to 40 per cent. at the end of the third hour, and about 54 per cent. at the end of 18 and 24 hr.

At another plant the losses for condensate ranging from a gravity of 79° to 98°Bé. were 0 to 19 per cent. for the first hour, 0 to 26 per cent. for 2 hr., 1 to 34 per cent. for 3 hr., 2 to 38 per cent.

for 4 hr., 3 to 45 per cent. for 6 hr., 4 to 48 per cent. for 7 hr., 4 to 46 per cent. for 8 hr., and 10 to 65 per cent. for 24 hr.

A slower rate of evaporation occurs from a mixture of refinery naphtha and a condensate than when the condensate is allowed to evaporate separately. In some tests conducted by Burrell, Seibert and Oberfell, the saving at the end of the first hour was about 6 per cent. in favor of the blends; at the end of the second hour, about 10 per cent.; at the end of the third hour, about 11 per cent.; at the end of the fourth hour, about 10 per cent.; at the end of the fifth hour, about 12 per cent.; at the end of the sixth hour, about 11 per cent.; at the end of the seventh hour, about 8 per cent.; and at the end of the twenty-fourth hour, about 14 per cent.

Vapor Pressures.—Freshly drawn condensates with a gravity of 93°Bé. may have a vapor pressure of 14 to 48 lb. per square inch at temperatures of 55° to 100°F. (13° to 38°C.). Condensates with a gravity of 78°Bé. may have vapor pressures ranging from 3 to 19 lb. per square inch at temperatures of 55° to 100°F. (13° to 38°C.). Condensates with a gravity of 78°Bé. may have vapor pressures ranging from 3 to 19 lb. per square inch at temperatures of 55° to 109°F. (13° to 43°C.).

After a condensate with a gravity of 93°Bé. has lost 40 per cent. of its volume by evaporation, the vapor pressures may range from 1 lb. to 19 lb. per square inch at temperatures ranging from 55° to 109°F. (13° to 43°C.).

When a freshly drawn condensate having a gravity of 93°Bé. is mixed with refinery naphtha with a gravity of 60°Bé., the vapor pressures may be 57 to 70 per cent. of the vapor pressure of the condensate alone. Condensates of the same specific gravity may have different vapor pressures.

The Transportation of Natural-Gas Gasoline.—The rules of the Interstate Commerce Commission regarding the shipment of natural-gas gasoline are as follows.

REGULATIONS FOR THE TRANSPORTATION ON RAILROADS OF NATURAL-GAS GASOLINE[1]

Liquefied petroleum gas is a condensate from the "casing-head gas" of petroleum oil wells, whose vapor tension at 100°F. (38°C.) (90°F.–

[1] From "Regulations of the Interstate Commerce Commission for the Transportation of Explosives and Other Dangerous Articles by Freight and by Express, and Specifications for Shipping Containers," published by the

32°C., Nov. 1 to Mar. 1) exceeds 10 lb. per square inch. Liquefied petroleum gas must be shipped in metal drums or barrels which comply with "Shipping-Container Specifications No. 5," or in tank cars especially constructed and approved for this service by the Master Car Builders' Association.

When the vapor tension at 100°F. (38°C.) exceeds 25 lb. per square inch, cylinders as prescribed for compressed gas must be used.

[The commission has not deemed it best at this time to prohibit the use of good wooden barrels in shipping inflammable liquids with a flash-point below 20°F. (−7°C.). It is, however, expected that their use for that purpose will be gradually discontinued and that within a reasonable time metal barrels will come into general use for such shipments.]

Packages containing inflammable liquids must not be entirely filled. Sufficient interior space must be left vacant to prevent distortion by containers when heated to a temperature of 120°F. (49°C.). This vacant space must not be less than 2 per cent. of the capacity of the container, including the dome capacity of tank cars.

1. The provisions of "Shipping-Container Specifications No. 5" apply to all containers specified therein that are purchased after Dec. 31, 1911, and used for the shipment of dangerous articles other than explosives. Each such container purchased subsequently to Dec. 31, 1911, shall have plainly stamped thereon the date of manufacture thereof.

2. An iron or steel barrel or drum with a capacity of from 50 to 55 gal. must have a minimum weight in the black, exclusive of the weight of rolling hoops, of 70 lb. and the minimum thickness of metal in any part of the completed barrel must not be less than that of No. 16 gauge United States standard.

3. An iron or steel barrel or drum with a capacity of from 100 to 110 gal. must have a minimum weight in the black, exclusive of the rolling hoops, of not less than 130 lb. and the minimum thickness of metal in any part of the completed barrel or drum must not be less than that of full No. 14 gauge United States standard.

4. Each barrel or drum must stand without leaking a manufacturers' test under water by interior compressed air at a pressure of not less than 15 lb. per square inch sustained for not less than 2 min., and the type of barrel or drum must be capable of standing without any serious permanent deformation and without leaking a hydrostatic test pressure of not less than 40 lb. per square inch, sustained for not less than 5 min.

5. When filled with water to 98 per cent. of its capacity, the type of barrel or drum must also be capable of standing without leakage a test drop on its chime for a height of 4 ft. upon a solid concrete foundation.

Bureau for the Safe Transportation of Explosives and Other Dangerous Articles, in January, **1912**, pp. 72, 143, 144, and 145. Effective Mar. 31, 1912.

6. Bungs and other openings must be provided with secure closing devices that will not permit leakage through them. Threaded metal plugs must be close fitting. Gaskets must be made of lead, leather, or other suitable material. Wooden plugs must be covered with a suitable coating and must have a driving fit into a tapered hole.

7. The method of manufacturing the barrel or drum and the materials used must be well adapted to producing a uniform product. Leaks in a new barrel or drum must not be stopped by soldering, but must be repaired by the method used in constructing the barrel or drum.